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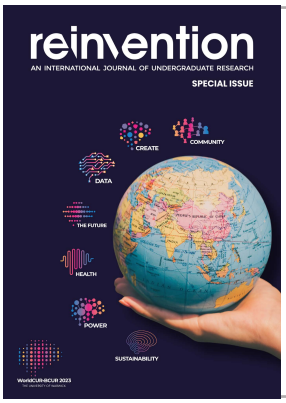

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Editorial

Global Minds: Expanding Beyond the Horizon

Yit Xiang Wong, University of Warwick

I am glad to announce that *Reinvention*'s Special Issue has now been published. This special issue, 'Global Minds: Expanding Beyond the Horizon', aims to place the spotlight on the 2023 World Conference on Undergraduate Research (WorldCUR) and the British Conference of Undergraduate Research (BCUR) held at the University of Warwick in April 2023 and hosted by the Institute for Advanced Teaching and Learning (IATL).

WorldCUR-BCUR was an event where the World Congress and the British Conference were brought together as a joint conference for the first time. Undergraduate researchers from across the globe and the UK travelled to Warwick to present and share their research. Some of them gave spoken presentations, others a poster presentation. Each of these presenters went through a rigorous selection process to be granted the opportunity to attend the event. This was the third World Congress on Undergraduate Research – previous iterations having been hosted by the University of Oldenburg in 2019 and Qatar University in 2016. BCUR is an annual conference that celebrates British undergraduate research, which originated in 2011.

I had the wonderful opportunity to attend WorldCUR-BCUR personally as part of Reinvention. The team was there to run a "Writing for Publication" workshop, and some members of the team also volunteered to chair the spoken presentations. The conference was more than just a short fifteen-minute presentation. After every presentation session, people would crowd around with the presenters to ask more questions about their research, share methodological challenges, institutional support, sources of research funding. There was a researcher from Singapore who even brought her resin-persevered bugs to share with the audience. Part of this is what made WorldCUR-BCUR unique. It provided a platform for undergraduates across the globe to share their research with a like-minded community.

The theme that we chose for this special issue is Global Minds: Expanding Beyond the Horizon. Horizon has a double meaning in this case. The first is our conventional understanding of horizon. The beauty of WorldCUR-BCUR is its ability to bring research ideas across the globe. Nabirye's research on breast cancer in Arua City, Uganda and Kosgei *et al.*'s research on Cattle Mastitis in Bomet County, Kenya reminds us how important it is to consider the role of research in regions beyond our horizons. The second definition of horizon is one of creativity. This is seen through Maudsley's study of porcupine nocturnal behaviours and Nyangoma and Oryema's unique use of glass in protection against radiation. These are innovative ideas that requires the most creative minds of undergraduates to discover.

In this edition, we highlight five brilliant pieces of work that were presented in the conference.

Halima Nabirye's 'Knowledge, Attitudes and Barriers of Breast Self-Examination Among Women in Nyio Ward, Arua City' investigated the cultural factors that affect breast cancer in Uganda. In Uganda, 89 per cent of women diagnosed with breast cancer are in advanced stages (III and IV), leading to a poor prognosis. This cross-sectional study reveals that the lack of breast self-examination was not due to the traditional belief of cultural stigmatisation, but rather a complete lack of awareness. Nabirye's research highlights the importance of scientific dissemination through multiple information channels.

Hannah Maudsley's 'The Effect of the Lunar Cycle on Nocturnal Behaviour in Captive Cape Porcupine (*Hystrix africaeaustralis*)' analyses the activity levels of porcupines in the Reaseheath Mini Zoo. The results found that there was an observed increase in maintenance and resting behaviours during full moons, which are linked to predator avoidance. Maudsley's research highlights the nuanced differences between species to maximise animal welfare in animal captive centres.

Judith Nyangoma and Bosco Oryema's 'A Comparative Study of Photon Radiation Shielding Properties of Different Glass Types for Use in Health Facilities' compared various materials to protect against radiation from X-ray and gamma-ray sources. The study compared the glass types phosphate, bismuthate, tellurite, silicate, and borate. It concluded that bismuthate glass is the most effective material for photon shielding in medical applications, while borate glass is the least effective.

Lauren Dowdeswell and Lucianna Churchill's 'The Influence of Harness Design on Forelimb Biomechanics in Pet Dogs' is a personal favourite of mine. Dowdeswell's research extends beyond the existing research on assistance dogs to pet dogs. The study showed that the straight-front harness allowed the greatest range of motion in the shoulder and elbow, while the front-clip harness restricted these movements the most. This has significant consequences on how we can enhance safety and prevent musculoskeletal disorders in dogs.

Nathan Kipkirui Kosgei, Peter Njuguna Ndirangu, Senerwa Daniel Mugangai and Christine M. Mbindyo's 'Prevalence of Clinical and Subclinical Cattle Mastitis and the Associated Risk Factors in Bomet County, Kenya' surveyed 75 cows from 50 farms, finding an overall mastitis prevalence of 16 per cent. Of these, 25 per cent had clinical mastitis, and 12 per cent had subclinical mastitis. The prevalence was higher in cattle raised under intensive systems (13.3 per cent) compared to those in semi-intensive systems (2.7 per cent). This is associated with poor milking practices and control methods, due to the farmers' lack of knowledge, that contributed to the prevalence of mastitis.

The beauty of WorldCUR-BCUR is as simple as our theme suggests. Undergraduates bring in new perspectives that push us to pursue more creative research ideas. International conferences allow us to see beyond the small geographical research bubbles to which, often, we limit ourselves. But most importantly, as both Kosgei *et al.* and Nabirye point out, only when we spread awareness about our research finding and implications do we allow for the improvement of society.

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Knowledge, Attitudes and Barriers of Breast Self-Examination Among Women in Nyio Ward, Arua City

Halima Nabirye, Muni University

Abstract

Breast self-examination (BSE) is an effective, inexpensive and simple screening technique for examining breasts monthly to detect breast cancer. Among women diagnosed with breast cancer in Uganda, 89 per cent of them present with stage III or IV, which has a poor prognosis. This study was conducted to assess knowledge, attitudes and barriers regarding BSE among women in Nyio ward, Arua City, Uganda.

A descriptive cross-sectional study was conducted among 354 women selected by cluster sampling and random walk method. Data was entered into Microsoft Excel, coded and analysed using the SPSS version 23. Knowledge of BSE among the participants was low. Less than half of the respondents (47.5 per cent) had ever heard about BSE as means of early detection of breast cancer and only 23.2 per cent knew how to perform BSE. The majority (95.8 per cent) had a positive attitude towards BSE practice, 85.7 per cent believed BSE is crucial in detecting breast cancer early, and most (83.3 per cent) agreed early detection increases the chances of long-term survival. The most common barrier towards BSE was lack of awareness.

A multidisciplinary approach, including the use of mass media, is required to create awareness about BSE and to reach a broader community.

Keywords: Knowledge of Breast self-Examination, Attitude towards breast self-Examination, Barriers to Breast self-Examination, Breast Self-Examination

Background

Breast cancer is the most often diagnosed and the leading cause of cancer mortality among women worldwide, accounting for 23 per cent of all cancer cases and 14 per cent of cancer deaths, with an annual incidence of 3 per cent and a death rate of 1.8 per cent (Atuhairwe *et al.*, 2018).

According to the World Health Organization, it is estimated that 2.3 million women were diagnosed with breast cancer globally in 2020, of which 685,000 succumbed to breast cancer (WHO, 2021). The annual estimates of age-standardised incidence rates per 100,000 women in Sub-Saharan Africa and Eastern Africa were 33.8 and 30.4, respectively (Azubuike *et al.*, 2018). In 12 Sub-Saharan African nations, 5-year age-standardised relative survival was 66 per cent for cases detected between 2008 and 2015, compared to 85 per cent to 90 per cent for cases diagnosed in high-income countries between 2010 and 2014 (Sung *et al.*, 2021). Eastern Africa has a breast cancer mortality rate of 15.4 per 100,000, with a 5-year breast cancer survival rate of 37.7 per cent, compared to 35.2 per cent and 48.1 per cent in West Africa and South Africa, respectively (Popli *et al.*, 2022).

The age-standardised incidence and death rates of breast cancer in Uganda, a low-income nation, are 21.3 per 100,000 population and 10.3 per 100,000 population, respectively, which shows that almost a half of Ugandan women diagnosed with breast cancer will die from the disease (Scheel *et al.*, 2020). Among women

diagnosed with breast cancer in Uganda, 89 per cent present at stage III or IV, which is more difficult to treat and has poor prognosis (Scheel *et al.*, 2020).

Mammography, clinical breast examination (CBE) and breast self-examination (BSE) are the most essential strategies for early identification of breast cancer. Mammography has long been considered the best option for early detection of breast cancer since it can detect the disease even before the woman notices a lump; however, because of its high cost and limited availability, this strategy is limited in developing countries (Boafo and Tetteh, 2020).

Early detection of the cancer when it has not spread to other parts of the body makes treatment more effective and increases the patient's quality of life and chances of survival. The most reliable and cost-effective strategy to detect breast cancer early is to have frequent BSEs (Alshahrani *et al.*, 2020). BSE is a non-invasive procedure in which women examine their breasts on a monthly basis between the seventh and tenth day of the menstrual cycle in order to discover any abnormal swelling or lumps; this enables them to seek medical help as soon as possible (Birhane *et al.*, 2017).

There is still a gap in early identification of breast cancer in Uganda. As such, women are seen to present with the disease in late stages, which probably could be attributed to lack of knowledge on BSE. Few studies have been published about knowledge, attitudes and barriers to BSE in Uganda and none in West Nile and in Arua City. The objective of this study is to assess the knowledge, attitudes and barriers to BSE among women in Nyio ward, Arua City.

Materials and methods

Study design

A descriptive cross-sectional study was conducted using quantitative methods.

Study setting and site

Nyio ward is located in Arua City, Uganda. As of the Uganda Bureau of Statistics (UBOS) 2020 projections, Arua had a population of 751000 with 52% being females The Illiteracy status rate in Arua is high at over 72 per cent among individuals aged ten years and above. There are two divisions in Arua City: Ayivu and Arua Central Division with 26 sub-counties. Most people in Ayivu Division are Christians, while the majority in Arua Central Division are Muslims.

Arua City comprises different ethnicities and races, such as the Lugbara, Alur, Kakwa, Madi, Indians, Sudanese, Congolese, Bantu, Langi and Acholi. Nyio ward has six villages – namely, Awulaka/Olivu, Aroyi, Muni, Nyio, Ofude and Ogayi, and the dominant tribe is Lugbara, which is their local language. Small-scale farming is done on fertile soils especially near the valleys and the slopes of the hills.

Target population

This included all females aged aged 18 years and above living in Nyio ward, Arua City.

Inclusion criteria

The subjects of this study were women who had been living in Nyio ward for the past 3 years, aged 18 years and above, had never suffered from breast cancer, and signed the consent form so as to participate out of their own free will.

Exclusion criteria

Those who were excluded from this study were women who were critically ill, mentally ill or had travelled out of the ward on the day of data collection.

Sample size determination

The sample size was estimated using the formula developed by Kish and Leslie (1965). Considering the reported prevalence of 35.2 per cent of women who knew how to perform breast self-examination in a study carried out in Kyadondo County (Atuhairwe *et al.*, 2018):

$N = \frac{Z2PQ}{D2}$

where:

N = Minimum required sample size

Z = Standard normal variable at (1-α) % confidence level and, α is mostly 5%, with 95% confidence level (standard value of 1.96)

D = Precision/margin of sample error -/+5%

P = Proportion prevalence of women who knew how to perform BSE 35.2%

Q = (1 – P) = 1-35.2% = 0.648

$N = \frac{(1.96)2x0.352(0.648)}{(0.05)2}$

N = 350.501 N= Approximately 351 participants.

Therefore, 59 participants were obtained from each of the six villages, which made a sample size of 354 participants.

Sampling procedure

A cluster sampling method was used in this study, starting with simple random sampling to select the sub-county and ward for the study. Among the 26 sub-counties, Oluko sub-county was randomly selected. Oluko sub-county had nine wards – namely, Ambeko, Anipi, Bunyu, Nyio, Ombokoro, Onzivu, Turu, Wandi and Yabiavoko. These wards were written on different pieces of paper and chosen randomly to select only one ward (Nyio ward). Participants were obtained from all the six villages in Nyio ward. Out of the 654 households in Nyio ward, the households which participated in the study were obtained by spinning a bottle in the village centre. Where the bottle top faced was the direction the researcher and the research assistants chose for data collection. We chose 59 participants to be studied studied from each of the six villages, making a total of 354 participants.

Data collection tools and procedure

After being granted permission by the administrators of Muni University, data was then collected. The principal investigator hired research assistants who were pursuing a bachelor's degree in nursing, and knew both Lugbara, the local language, and English. The research assistants were trained for 2 hours about the research topic, data collection tools, and obtainig informed consent. Before data collection, the principal investigator and the research assistants first sought permission from the Local Council I (LCI) of the villages. Thereafter the principal investigator and the research assistants were given Guides from each village to take them to the households.

Households were counted following a straight line until the village boundary. A number was chosen randomly between one and the total number of houses counted. The number of the house selected randomly was the first house which was surveyed. Subsequent households were chosen by continuing away from the village centre. Only houses on the left side of the road were included. The research assistants would turn left each time a road was encountered on the left side. This was continued until all the 59 participants were obtained.

Every component of the research was explained to the participants, including the objectives of the study, the benefits, any negative effects and what was expected from them. Verbal and written consent was obtained from the participants to take part in the study by the research assistants. Participants who met the eligibility criteria were interviewed using interviewer-administered questionnaires with both open and closed questions after establishment of a rapport in a quiet environment. Each participant took a maximum of 20 minutes to answer the questions in the questionnaire.

Every participant was thanked by the research assistants after the questionnaire had been filled. Then the research assistants moved on to the next house until the desired sample size was attained. All research assistants returned the questionnaires to the principal investigator after data collection to work on the data management process. Data collection in each village was done over 2 days, during which 29 participants were interviewed on the first day and 30 on the second day.

Data management

Data storage and processing

The completed questionnaires were identified by numbering them from 1 to 354 and entered in Microsoft Excel.

Data analysis

Once collected data was entered into Microsoft Excel, it was cleaned, coded and imported to SPSS version 23 statistical package for analysis. Univariate analysis was used for data analysis using mean (standard deviation), frequencies and proportion for categorical variables.

Data presentation

Statistical frequency distribution tables, graphs and charts were used for data presentation in terms of proportions, absolute values and percentages.

Data quality and control

Different measures of data quality control were applied to ensure validity and reliability of the data that was collected.

Reliability: The principal investigator and the research assistants carried out a pre-visit and a pre-test of the questionnaire before data collection and editing of work at the end of each data collection day to ensure its reliability (Polit and Beck, 2017). A pre-testing survey was conducted, and 30 participants were selected to take part (Perneger *et al.*, 2015). Ten participants were obtained by convenience sampling from each of Awindiri, Ayibiri and Euata villages within Onzivu ward making a total of 30 participants. Questions were developed according to the objectives and reviewed literature.

Validity: A content validity index (CVI) was used to test the questionnaire's validity, as shown in the formula below.

$$\text{CVI} = \frac{\text{Number of questions declared valid}}{\text{Total number of questions in the questionnaire}}$$

A minimum of 0.75 of content validity index was used to confirm validity (Lawshe, 1975). The questionnaire was translated into Lugbara, the local language spoken by the majority of Nyio ward women.

The research assistants were bachelor's degree holders of nursing and fluent in both Lugbara and English languages.

Participant's responses were recorded as soon as they were given. After the interviews were completed, the researcher double checked all of the questionnaires for accuracy before storing them.

Ethical considerations

Ethical clearance was obtained from the Department of Nursing and Midwifery, Muni University. Authorisation to conduct the study in Nyio ward was obtained from the Town Clerk and from the Local Council of one of each of the villages.

Study participants had to consent by signing/ putting a thumbprint on the on written consent forms and questionnaires were anonymised.

Results

Socio-demographic characteristics of respondents

A total of 354 females – 16.7 per cent from each village – responded to the questionnaire with a response rate of 100 per cent. The mean age of the respondents was 29 years. The minimum age was 18 years while the maximum was 83 years. The majority of the respondents were of the Lugbara tribe (90.1 per cent); 47.2 per cent were Catholics and more than half (54.2 per cent) were married. In terms of education, the largest proportion stopped at primary education (39.8 per cent), 37.0 per cent had informal occupations and 31.1 per cent had no children, as shown in Table 1.

Variable	Frequency	Percentage %
Age group in years		
18-28	213	**60.2%**
29-39	83	23.4%
40-50	42	11.9%
51+	16	4.5%
Tribe		
Lugbara	319	**90.1%**
Madi	8	2.3%
Kakwa	13	3.7%
Alur	6	1.7%
Others	8	2.3%
Religion		
Catholic	167	**47.2%**
Islam	22	6.2%
Protestant	156	44.1%
Other	9	2.5%
Marital status		
Single	120	33.9%
Married	192	**54.2%**
Divorced	23	6.5%
Widowed	19	5.4%
Level of education		
None	53	15.0%
Primary	141	**39.8%**
Secondary	77	21.8%
Tertiary	83	23.4%
Occupation		
House wife	83	23.4%

Formal	62	17.5%
Informal	131	**37.0%**
Student	78	22.0%
Number of children		
0	110	**31.1%**
1-2	107	30.2%
3-4	77	21.8%
5-6	50	14.1%
7+	10	2.8%

Table 1: Socio-demographic characteristics of study participants in Nyio ward.

Knowledge of breast self-examination

Most of the respondents (96.6 per cent) had heard about breast cancer although only 16.7 per cent had ever had a family member diagnosed with breast cancer. Less than half of the respondents (47.5 per cent) reported having heard about Breast Self-Examination (BSE) as a means of early detection of breast cancer. Only 23.2 per cent (n=39) of the 168 respondents who had heard of BSE knew how to perform the examination. Out of the 39 respondents who knew how to perform BSE, 13 (33.3 per cent) knew when to perform BSE and only 3 (7.7 per cent) correctly reported the five major steps of BSE. A few of the 354 women (20.1 per cent) reported knowing how to identify lumps in the breast. (See Table 2.)

Among the 13 respondents who reported knowing when to perform BSE only 9 (69.2 per cent) reported correctly that it is performed ‘after menstruation’. One person (7.7 per cent) reported ‘anytime’, 1 (7.7 per cent) reported ‘every three months during pregnancy’ and 2 people (15.4 per cent) reported ‘before menstruation’ (See Table 3). Figure 1 shows that out of the 168 respondents who had heard about BSE, 30.5 per cent obtained the information from mass media (News, Radio or Television, WhatsApp, Twitter) and some had more than one source of information. Other sources of information were through community talks and gatherings.

Variable		Frequency	Percentage %
Heard of breast cancer	YES NO	342 12	**96.6%** 3.4%
Ever had a family member diagnosed with breast cancer	YES NO	59 295	16.7% **83.3%**
Heard of BSE as means of early detection of breast cancer	YES NO	168 186	47.5% **52.5%**
Know how to perform BSE	YES NO	39 129	23.2% **76.8%**
Know when to perform BSE	YES NO	13 26	33.3% **66.7%**
Know the 5 major steps of BSE	YES NO	3 36	7.7% **92.3%**
Know how to identify lumps	YES NO	71 283	20.1% **79.9%**

Table 2: Knowledge of breast self-examination among females in Nyio ward.

If yes, when to perform BSE	Frequency	Percentage %
After menstruation	9	69.2%
Anytime	1	7.7%
Every three months during pregnancy	1	7.7%
Before menstruation	2	15.4%

Table 3: Responses from participants who stated knowing when to perform BSE.

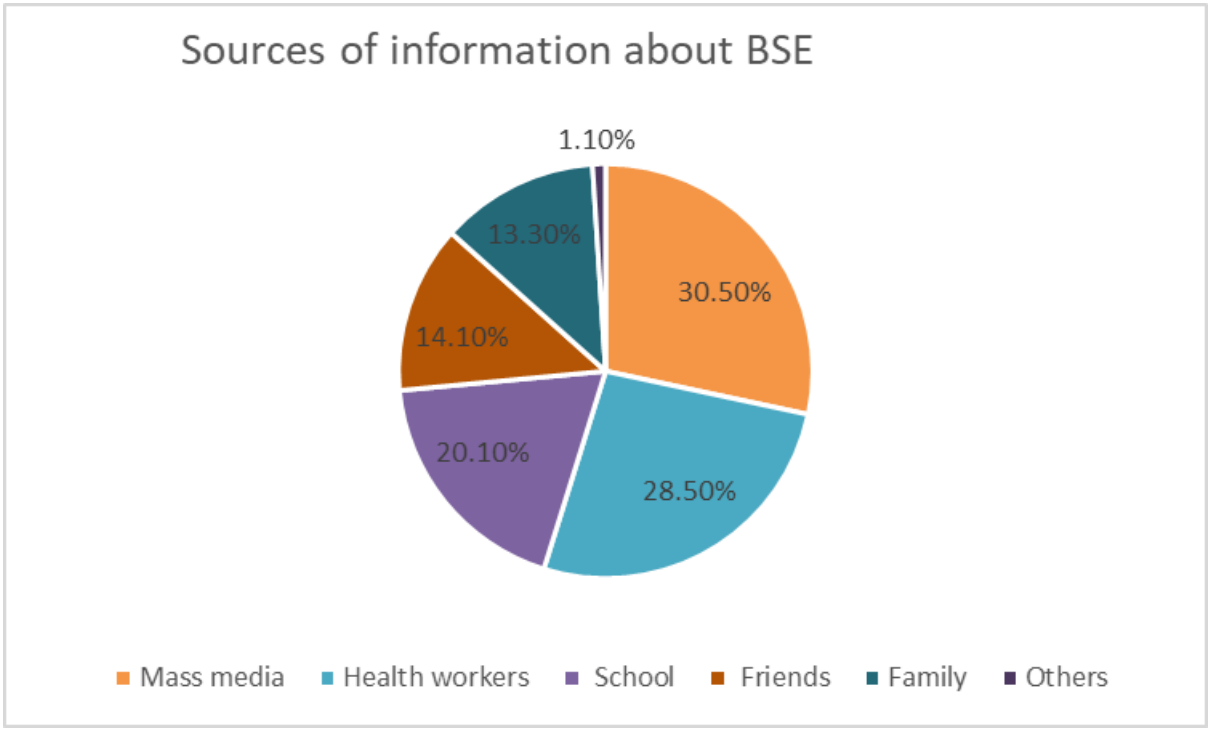

Figure 1: Showing the sources of information about BSE among females in Nyio ward

Attitudes towards breast self-examination

In Figure 2, out of the 168 respondents who had heard of BSE as a means of early breast detection, the majority of the respondents (95.8 per cent) had a positive attitude that BSE is a good practice and believed all women should examine themselves. Many respondents (41.7 per cent) agreed they would perform BSE if they had any risk of breast cancer, 29.2 per cent said they would if there was a cure and 28.0 per cent agreed they would perform BSE if their family approved it. The largest proportion (85.7 per cent) were positive that BSE is important and useful to detect breast cancer early and most (83.3 per cent) believed early detection increases the chance of long-term survival. Less than a half (25.0 per cent) of respondents believed that BSE is not necessary to perform if one has no problems with the breasts. A few (19.6 per cent) of the respondents felt that BSE should only be performed by women over 20 years. A few (3.6 per cent) acknowledged that they did not like to practice BSE because they were afraid – they may discover breast cancer in themselves – while 7.1 per cent did not like to practice BSE even though they were fully aware of its benefits. Only 18.5 per cent reported that performing BSE made them feel funny, or unpleasant, disgraceful and embarrassed because it requires them to touch their breast. All respondents reported they would go to the health facility if there were any symptoms of breast cancer.

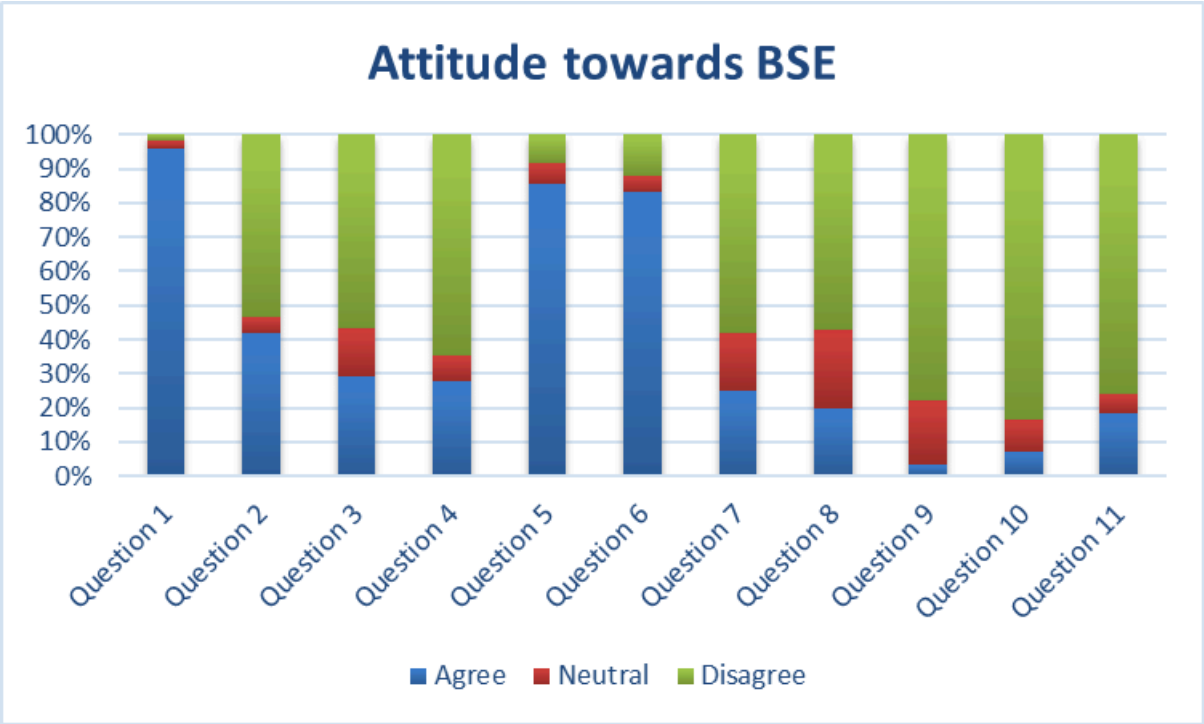

Figure 2: Showing the attitude of females in Nyio ward towards breast self-examination.

Question 1: BSE is a good practice

Question 2: Perform BSE if having a risk

Question 3: Perform BSE if there was a cure

Question 4: Perform BSE if family approve

Question 5: BSE is good to detect breast cancer early

Question 6: Early detection, high chance of survival

Question 7: BSE not needed if no problems with breast

Question 8: BSE for women over 20 years

Question 9: Afraid to discover breast cancer

Question 10: Know it's benefits but don't like to practice BSE

Question 11: Funny, unpleasant, disgraceful and embarrassing to touch breast

Barriers to breast self-examination

Table 4 shows that, out of the 354 participants, the majority (92.4 per cent) lacked awareness about BSE technique. Less than a half (28.2 per cent) lacked self-confidence, and a few (12.4 per cent) had discomfort with breast manipulation. Half (50.3 per cent) of the respondents never knew the importance of BSE while 47.7 per cent reported low education levels on the subject. A high proportion (74.0 per cent) of respondents reported lack of advice from health care workers to perform BSE, 31.6 per cent were afraid of touching lumps and detecting breast cancer and a few (15.5 per cent) had forgetfulness. Only 28.2 per cent reported

negligence and 44.4 per cent lacked time to practice BSE. Most respondents (79.4 per cent) did not receive trainings from health facilities and 17.2 per cent were afraid of pain during BSE.

Barriers towards BSE		Frequency	Percentage %
Lack of awareness about BSE technique	YES	327	**92.4%**
	NO	27	7.6%
Lack of self-confidence	YES	100	28.2%
	NO	254	**71.8%**
Discomfort with breast manipulation	YES	44	12.4%
	NO	310	**87.6%**
Not knowing the importance of BSE	YES	178	**50.3%**
	NO	176	49.7%
Low education level	YES	169	47.7%
	NO	185	**52.3%**
Lack of advice from health care workers	YES	262	**74.0%**
	NO	92	26.0%
Fear of touching lumps and detecting breast cancer	YES	112	31.6%
	NO	242	**68.4%**
Forgetfulness	YES	55	15.5%
	NO	299	**84.5%**
Negligence	YES	100	28.2%
	NO	254	**71.8%**
Lack of time	YES	157	44.4%
	NO	197	**55.6%**
Lack of training from health facilities	YES	281	**79.4%**
	NO	73	20.6%
Fear of pain during BSE.	YES	61	17.2%
	NO	293	**82.8%**
Others	YES	3	0.8%
	NO	351	**99.2%**

Table 4: Barriers towards BSE practice among women in Nyio ward.

Discussion of results

Knowledge of breast self-examination

The study findings indicate that few participants were aware of breast self-examination as a means of early detection of breast cancer. This outcome is supported by the findings of Suleiman (2014), a study conducted among Jordanian women which showed that only 34.9 per cent were aware of BSE as a means for early detection. This may have been because of the low levels of education attained by the women who participated in the study. In addition, Joyce *et al.* (2020) found that knowledge of BSE was low (39.4 per cent) among 386 women above 18 years in Eastern Uganda. Since this paper shows that most participants stopped

at primary level of education, it was possible that they would have low awareness about BSE compared to other populations. The study conducted among nursing and clinical nutrition students in Gaza indicated conflicting findings that the vast majority of respondents (96.5 per cent) had a high knowledge about BSE *Abo Al-Shiekh et al., 2021*. This could have been because these students were taught in medical schools, thus they may have had prior sessions about BSE. The results obtained emphasise the need for increased awareness and promotion of BSE practices among women, particularly in regions with limited access to healthcare services.

As seen in Figure 1, the main source of information given to participants was through mass media, followed by health workers. This is in agreement with a retrospective study carried out in Saudi Arabia among 508 participants which revealed that more than half of the participants (53.62 per cent) obtained the information about BSE through social media and 18.84 per cent through the medical staff (Alshahrani *et al.*, 2020). Our study findings were contrary to the findings of the study carried out in Eastern Uganda Joyce et al., (2020), which revealed that health workers were the primary source of information (55.9 per cent) followed by News/media (23 per cent). The differences in findings may be due to the study setting since the study was conducted in a hospital, which may have introduced biases among respondents. Although health workers remain a crucial source of information, making use of mass media can increase awareness and reach a broader audience – especially in rural communities.

Only a few respondents (11 per cent) knew how to perform BSE; this is contrary to the study done by Joyce *et al.* (2020), which showed that 58.6 per cent of the respondents knew how to perform BSE. Among those who knew how to perform BSE, less than half of the respondents stated correctly that BSE should be performed a week after the start of menses. This is different from the findings of Abo Al-Shiekh *et al.* (2021) who studied knowledge of female nursing and clinical nutrition university students, which revealed that 69.8 per cent knew when to perform BSE. This is probably because nursing and clinical nutrition students may have heard about BSE from school and the training hospitals, and they are more sensitised in terms of disease and its preventive measures. Also, according to Joyce *et al.* (2020), only a few of the respondents (11.8 per cent) reported correctly that it should be done one week after menstruation.

The findings of this study indicated that only three of the respondents reported correctly the five major steps of BSE. The study findings of Abo Al-Shiekh *et al.* (2021) revealed that 22.1 per cent of the respondents could correctly apply the steps of BSE. In another survey conducted among 308 students from the University of Ghana, 98.7 per cent students admitted that they were sure of the steps to follow during BSE and could identify a lump by performing BSE (Boafo and Tetteh, 2020). From the reviewed literature, most of the studies did not attempt to assess the exact steps of BSE among the participants. Therefore, it cannot be concluded whether the participants knew the five major steps of BSE. Twenty percent of respondents in this study reported knowing how to identify lumps in the breast. This is less than the findings of Atuhairwe *et al.* (2018) in a household survey of women in Kyadondo County, Central region, Uganda, which showed that 35.2 per cent of the women knew how to check their own breasts for lumps. The findings suggest that there is need to pay attention to steps involved in BSE and how to identify lumps during training sessions.

Attitude towards breast self-examination

Findings in this study showed that most participants agreed BSE is a good practice for all women. This is similar with the findings of a study conducted among 420 female university students in Ethiopia which revealed that most of the study participants (96.5 per cent) agreed that BSE is important and beneficial for

detecting breast cancer (Birhane *et al.*, 2017). Another in study in Saudi Arabia that surveyed 508 participants revealed similar results where 95.28 per cent of the respondents agreed that early identification of breast cancer boosts the likelihood of recovery (Alshahrani *et al.*, 2020). Through BSE awareness, most misconceptions about breast cancer and BSE can be cleared, ultimately promoting its practice and contributing to better health outcomes.

Although the majority of the participants agreed that BSE was a good practice, few did not like to practice it despite being fully aware of its benefits. A greater proportion believed that BSE is important and useful to detect breast cancer early, and that early detection increases the chance of long-term survival. This is similar to the study by Birhane *et al.* (2017) which showed that 89.9 per cent of the respondents believed that early identification increases the chances of long-term survival. Also, the findings by Alshahrani *et al.* (2020) revealed that 95.28 per cent of the respondents believed early identification of breast cancer boosts the likelihood of recovery. By encouraging women to practice BSE, healthcare providers can empower them to take proactive steps towards early detection and treatment, potentially improving breast cancer outcomes.

In our study, not many women would practice BSE if their family did not approve it and only a few would practice it only if there was a known cure for the disease. This is similar with the findings of Suleiman (2014) who found that 25.5 per cent of the respondents would practice BSE if their family approved and 19.3 per cent only if there was a known cure for \the disease in a study he conducted among 900 female Jordanian students from the University of Jordan in Amman. The participants in his study were enrolled voluntarily, which could have made the results biased and the students who chose to participate may have had different attitudes towards BSE than those who did not volunteer.

Hardly any participants acknowledged fear of discovering breast cancer in themselves. Similar findings were obtained by Waswa (2017) in a study among women aged 18–45 years in gynaecological ward at KIU-teaching hospital in Uganda which revealed that most (75 per cent) of the participants feared being diagnosed with breast cancer and thus did not perform BSE. In this study, few (25.0 per cent) reported it was not necessary to perform BSE for those who had no breasts problems, which is similar to the findings of the same study by Waswa (2017 with 11.5 per cent of participants believing that it was not necessary if one had no problems with the breast. A small number reported feeling funny, unpleasant, disgraceful and embarrassed while preforming BSE. This is contrary to the findings of Waswa, 2017 where none of the participants reported the above with BSE practice. The differences in the results may be because the current study was conducted in villages whereas Waswa's study was conducted in a hospital and a more urban setting, therefore a practice of wellness could not have been considered funny, unpleasant, disgraceful and embarrassing. The findings also suggest that women in rural settings may face unique barriers when practicing BSE, which may need to be addressed through targeted education and awareness efforts.

In our study, few (19.6 per cent) respondents believed BSE should only be performed by women over 20 years. Meanwhile Alshahrani *et al.*, 2020 reported that 76.18 per cent of the participants agreed that women over the age of 20 should conduct BSE. This could have been due to limited knowledge about BSE among the participants in the current study, thus they may have not known the right age for performing BSE regularly.

All of the respondents said they would visit a health facility if they noticed any signs of breast cancer. Similar results were obtained by Birhane *et al.* (2017) who found that nearly all respondents (96.8 per cent) stated they would visit a health facility if they experienced any signs or symptoms of breast cancer.

Barriers to breast self-examination

In this study, the majority of the participants reported a lack of awareness about BSE technique, a few lacked self-confidences, a minority had discomfort with breast manipulation and more than half the respondents didn't know about the importance of BSE. In line with these findings, a study carried out among 52 women in Kampala, Uganda revealed that more than a half (65 per cent) did not practice BSE due to lack of information about how to perform BSE, 15 per cent lacked self-confidence and a few (10 per cent) had discomfort with breast manipulation (Waswa, 2017). On the other hand, only 8 per cent of the participants in the same study didn't know the importance of examining breasts (Waswa, 2017). These findings highlight the necessity of including breast cancer screening techniques in the sensitisation sessions by healthcare providers and regularly raising community awareness of BSE and its advantages.

Almost half of the participants in our study with low education level had no access to information about BSE, thus hindering their practice. This is consistent with the findings of Shakti Yambem and Rahman (2019) who surveyed 302 Sikkimese women in India. Their study revealed that education level is among the significant predictors of BSE. Out of the 302 women, 172 women had a low education level ($<12^{th}$ standard) and 130 women had a high education level ($>12^{th}$ standard). Those with a low education level showed 9.3 per cent of women who had practiced BSE and 90.7 per cent who had never self-examined. Of those with a high education level, 31.5 per cent had practised BSE and 68.5 per cent had never self-examined (Shakti Yambem and Rahman, 2019). Women who had attained a higher education level embraced BSE practice due to a prior awareness compared to those who did not.

The results from our study showed that a few of the respondents cited forgetfulness, negligence as reasons why they did not practise BSE. Almost half lacked time to self-examine, most reported a lack of advice from health care workers to perform BSE and the majority did not receive trainings from health facilities. Not many of the participants were afraid of touching lumps and detecting breast cancer and only a few were afraid of experiencing pain during BSE. Consistent with these results, a study by Taleghani *et al.* (2019) of 202 Iranian women from rural areas in Isfahan city, 21.30 per cent women mentioned lack of awareness about BSE techniques, 37.60 per cent cited forgetfulness and negligence, 25.7 per cent reported a lack of time or being too busy, 8.90 per cent were afraid of touching lumps and detecting breast cancer and only 8.40 per cent were afraid of pain during BSE. The same study reported that only 13.40 per cent mentioned lack of training by health care workers, which does not correlate with the findings of our study. In another study some women blamed their family physician for not advising them to perform BSE (Shakti Yambem and Rahman, 2019).

Despite the study by Taleghani *et al.* (2019) being conducted in the suburbs of the city, only 5.3 per cent of the women were illiterate compared to the current study where 15.0 per cent had never gone to school. Education level is significantly associated with some barriers to BSE. Women having a high education level were more likely to practise BSE than those with lower education, and women with lower levels of education also have poor understanding of behaviours associated with early detection of breast cancer. The specific demographic characteristics of women should be taken into account while designing nursing strategies and interventions to prevent BSE.

There is also a need to make individualised approaches to handle factors that may hinder BSE practice among women.

Dissemination of the study results

The research findings were disseminated to the faculty of health sciences in the department of Nursing and Midwifery of Muni University. Results from the study were submitted to Muni University as a partial fulfilment of the requirement for the award of a bachelor's degree in nursing and Nyio community through a meeting. It was also presented in the WorldCUR-BCUR conference 2023 at the University of Warwick in United Kingdom.

Limitations of the study

Most variables were measured by the participants' subjective report which may have led to introduction of observation and recall bias. BSE was explained to some participants who raised questions, thus some of the findings could have been affected due to having prior information.

Conclusion and recommendations

Despite a significant proportion of participants having heard about breast cancer, and having a positive attitude towards Breast Self-Examination, BSE practice is still very low. Lack of awareness is a primary barrier towards BSE practice highlighting a need for health professionals to raise community awareness about BSE, its significance, techniques and steps involved.

Health workers are urged to implement BSE health education programmes within the healthcare facilities. Since most women in rural areas have access to mass media such as radios, it is recommended to promote public breast health awareness campaigns through the media.

There is a need to conduct research to assess the impact of women's demographics like age, level of education and economic status on BSE practice.

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Appendix I: Consent form

Investigator's Name: _____

Student number: _____

Address: Muni village, Nyio ward, Oluko Subcounty, Arua City

I am asking for your voluntary participation in my research project. Please read the following information about the study.

Research Title: **Knowledge, Attitude and Barriers of Breast Self-Examination Among Women in Nyio Ward, Arua City**

Study objective

To assess knowledge, attitude and barriers of breast self-examination among women in Nyio ward, Arua City.

Purpose of the study

This research will generate information which will be used by health facilities and community health services to create awareness about breast cancer and the basic screening services available. This study will encourage the women within the community to understand and practice BSE such that in case of any unusual breast findings they report early to the health care facilities for prompt management, thus reducing breast cancer morbidity and mortality.

Health workers might also be encouraged to pay more attention to clinical breast examination and teach women how to perform BSE especially where there are identified risk factors. This study will also guide future researchers on the different aspects to study about which may affect BSE practice among the different communities.

If you accept to participate, you will be asked to:

Give honest and truthful responses to all the questions in the questionnaire. You will not be judged for the answers you submit but the investigator and research assistant will offer guidance where necessary to clear any misconceptions

Benefits of participating in the study

There will be no direct benefits for participation; however, the findings will be presented to Nyio community through a meeting. It will also be presented in conferences, seminars and workshops, published in scientific journals and social media platforms like Facebook, WhatsApp and Twitter.

Risks

We do not anticipate any risks in this study, but some questions might have negative mental effects during in some individuals.

How confidentiality will be maintained

This study has been approved by the Department of Nursing and Midwifery in partial fulfilment of the award of bachelor degree in nursing sciences at Muni University. It will be conducted according to the ethical guidelines and principals. Only the researcher will have access to the data obtained in this study and the questionnaires will be kept in a locked place to prevent unauthorised persons from accessing them. The participant's identity will remain anonymous in any report on the results of this research. This will be done by giving questionnaires numbers from 1 to 354.

If you would like to participate, please sign in the box below.

Voluntary Participation:

Participation in this study is completely voluntary. If you decide not to participate there will not be any negative consequences. Please be aware that if you decide to participate, you may stop participating at any time during the course of the study and you may decide not to answer any specific questions.

I understand that I am free to contact any of the people involved in the research to seek further clarification and information about names, degrees, affiliations and contact details of researchers (and academic supervisors when relevant).

By signing this form, I am attesting that I have read and understand the information above in the language I understand and I freely give my consent to participate in this study.

Participant's Name _____ Signature/thumb print_____

Date Consented _____

If you have any questions about this study, feel free to contact;

Telephone: _____ **Email:**

_____

Signature of researcher

I believe the participant is giving informed consent to participate in this study.

Signature of researcher and Date: _____

Appendix II: Questionnaire

A Questionnaire to Study the Knowledge, Attitude and Barriers of Breast Self-examination among women in Nyio ward

PART ONE: Socio-demographics

Circle one of the options for the questions below and fill in where appropriate

Age: _____ Tribe: _____

Religion: a) Catholic b) Islam c) Protestant d) Others, please specify_____

Marital status: a) single b) married c) divorced d) widowed

Level of education: a) None b) Primary c) Secondary d) Tertiary

Occupation:_____

Place of residence (village): _____

Number of children: _____

PART TWO: Knowledge about Breast Self-examination (BSE)

Circle one of the options for the questions below and write where appropriate

Have you ever heard of breast cancer?

a) YES b) NO

Do you have any family member who was diagnosed with breast cancer?

a) YES b) NO

Have you ever heard of Breast Self-examination as a means of early breast cancer detection?

a) YES b) NO

Do you know how to perform Breast Self-examination?

a) YES b) NO

Do you know when Breast Self-examination is supposed to be performed?

b) YES b) NO

If YES, when should Breast Self-examination be performed?

_____

Do you know the five major steps of breast self-examination?

a) NO **b) YES**

Do you know how to identify lumps in the breast during breast self-examination?

a) NO b) YES

What sources of information do you have for Breast Self-examination? Circle all that apply

a) Mass media (News, Radio or Television, WhatsApp, Twitter)

b) Health workers

c) School

d) Friends

e) Family

f) Others, Please specify

PART THREE: Attitude towards Breast Self-examination (BSE)

For this part, indicate a tick below the different responses (chose one in each section)

Questions	**Response**				
	Strongly disagree (1)	Disagree (2)	I do not Know (3)	Agree (4)	Strongly agree (5)
Breast self-examination is a good practice; therefore, all women should practice it					
I would perform BSE if I had any risk factor to breast cancer					
I would perform BSE if there was a known cure to breast cancer					
I would perform BSE if my family approved it					
BSE is important and useful to detect breast cancer early					
Early detection will increase the chance of long-term survival					
BSE is not necessary to perform if one has no problems with the breasts					
BSE is supposed to be performed by women over 20 years					
I do not like to practice BSE because I am afraid that I may discover breast cancer on myself					
I do not like to practice BSE even though am fully aware of its benefits					
Performing BSE makes me feel so funny, or unpleasant, disgraceful and embarrassed because it makes me touch my breast					

Where would you go, if there are any symptoms of breast cancer?

a) Health facility

b) Traditional healer

c) Hide it

d) Other, Please specify

PART FOUR: Barriers towards Breast Self-examination (BSE)

What are the reasons that prevent you from performing Breast Self-examination? Circle all that apply

a) Lack of awareness about BSE technique

b) Lack of self-confidence

c) Discomfort with breast manipulation

d) Not knowing the importance of BSE

e) Low education level

f) Poor socio-economic status

g) Lack of advice from health care workers

h) Fear of touching lumps and detecting breast cancer

i) Forgetfulness

j) Negligence

k) Lack of time

l) Lack of training from health facilities

m) Fear of pain during BSE

n) Others, please specify below

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Glossary

5-year age standardised relative survival: This refers to the probability of being alive in 5 years after a cancer diagnosis compared with the experience of the general population

Age standardised rates: are hypothetical rates that would have been observed if the populations being studied had the same age distribution as the standard population, while all other factors remained unchanged.

Attitude: A settled way of feeling or thinking about something, typically reflected in a person's behaviour.

Barrier: This is something/situation that makes it difficult or impossible for something to happen or be achieved.

Breast self-examination: Is a screening method used in an attempt to detect early breast cancer involving a woman her self-looking at and feeling each breast for possible lumps, distortion or swelling.

Clinical breast examination: This is the physical examination of the breastmdone by a health care provider.

Content validity index (CVI):Is the extent of a measurement tool represents the measured construct and it is considered as essential evidence to support the validity of a measurement tool such as a questionnaire for research.

Knowledge: Facts, information and skills acquired by a person through experience or education.

Local Council 1 (LC 1): This is the lowest level of local government administration responsible for governing the village

Mammography: Is a technique of using low-energy X-rays to examine the human breast for screening and diagnosis of breast cancer

Women: These are adult female human beings 18 years and above.

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The Effect of the Lunar Cycle on Nocturnal Behaviour in Captive Cape Porcupine (*Hystrix africaeaustralis*)

Hannah Maudsley, University Centre Reaseheath

Abstract

This study determined if a relationship between observed behaviours and lunar phases was present in captive Cape Porcupines *(Hystrix africaeaustralis),* a nocturnal species found in UK collections. Previous research on wild populations of *hystrix* species found that the amount of moonlight a lunar phase presents can limit activity levels. Field studies found that the correlation can be an evolved predatory avoidance tactic in response to moonlight exposure. A captive study aids in comprehending diel cycles and the factors which influence them, as behaviours are not limited to high moonlight phases. Between November 2022 and March 2023, recordings of nocturnal behaviours on dates surrounding distinct lunar phases took place at Reaseheath Mini Zoo. An ethogram based on previous behaviour studies identified behaviours. Data was then analysed using General Linear Regression (GLR). The study aimed to discover if a higher frequency of behaviours would correlate with lunar phases displaying higher levels of moonlight. Although GLMs proved insignificant, the data showed the rate of maintenance and resting behaviours increased during full moons, behaviours associated with predatory avoidance. Findings can provide information on lunar-behaviour relationships in captivity to benefit species-specific care and animal welfare by facilitating environmental challenge, competency and agency or alleviating moonlight-induced stressors to benefit affective welfare states.

Keywords: Hystrix afrucaeaustralis, Temporal, Lunar, Behavioural

Introduction

Nocturnality is present in most extant mammals and is perceived to be an ancestral trait originating from therapsids in the Triassic period (Angielczyk and Schmitz, 2014; Lovegrove, 2019). The most common theory for mammalian nocturnal evolution is the 'nocturnal bottleneck hypothesis', which describes how early mammalians used nocturnality and developed corresponding traits in response to predatory threats from diurnal reptiles (Gerkema *et al.*, 2013; Hall *et al.*, 2012). The main argument supporting this theory is that fossil evidence indicates endothermy in mammalian ancestors, developed due to the limited nocturnal activity of early reptiles due to their ectothermic nature and reliance on solar activity (Clarke and Pörtner, 2010; Gerkema *et al.*, 2013). After the end-Cretaceous extinction event caused predatory reptilians to go extinct, mammals began to radiate and take back non-nocturnal diel cycles (Gerkema *et al.*, 2013). Research in photopigment evolution found that before early mammals became nocturnal, their ancestors displayed more crepuscular diel cycles, a supportive process for this evolutionary theory (Angielczyk and Schmitz, 2014; Gerkema *et al.*, 2013; Lillegraven *et al.*, 1979). Not requiring high visual sharpness associated with daytime activity, most extant mammals, whether diurnal, nocturnal, crepuscular or cathemeral, have retained nocturnal traits and evolved specialisation in other sensory systems (Hall *et al.*, 2012; Torres and Clarke, 2018). With sensory systems adapted for nightlife, nocturnal animals are affected by different environmental cues than diurnal species (Monterroso *et al.*, 2013).

Environmental cues can alter behavioural rhythms (circadian/circannual), affecting how animals interact and respond to their environment (Alcock and Rubenstein, 2019: Gandia *et al.*, 2023).

An example of an environmental cue that affects nocturnal species is the lunar cycle (Kronfeld-Schor *et al.*, 2013; Palmer *et al.*, 2017). Because the Moon orbits the Earth, light reflected from the Sun to the Moon over 29.53 days creates a cycle of visibly different phases; the lunar cycle (Mayoral *et al.*, 2020). The main lunar phases include the full and new moons and the first and third quarter moons, with the first and third quarters producing an identical amount of moonlight (Mayoral *et al.*, 2020). The lunar cycle can affect the behavioural rhythms of mammalian predators and prey. On nights with higher luminosity, a prey species will limit behaviours that may lead to interactions with predators (Palmer *et al.*, 2017; Alcock and Rubenstein, 2019). Yet, predator species such as African Lions (*Panthera leo*) have a higher success rate when hunting with little moonlight (Packer *et al.*, 2011). Theories imply that the abiotic environmental cue of the lunar cycle has led to trophic coevolution of behaviours to increase predatory and prey success (Halle, 2000; Packer *et al.*, 2011; Palmer *et al.*, 2017; Rubenstein and Alcock, 2019).

The Cape Porcupine (*Hystrix africaeaustralis*) is a nocturnal mammal within the family Hystricidae under the order Rodentia (Wilson and Reeder, 2005). The species distribution ranges across southern Africa, inhabiting desert, shrubland and grassland habitats (Roze, 2014; Cassola, 2016; Coppola *et al.*, 2019). A field study on the effects of moonlight and seasonality on the temporal activity of Indian crested porcupines found different levels of moonlight exposure caused variations in behaviour (Alkon and Mitrani, 1988).

Results showed that the porcupines were more active during winter months when moonlight exposure was at its lowest as predation risk was at its lowest (Alkon and Mitrani, 1988).

More recently, another field study on the species found moonlight avoidance across four different study sites and found a significant relationship between the behaviour and the phases of the lunar cycle (Mori *et al.*, 2014). During full moons, activity levels were notably lower than those with less moonlight exposure (Alkon and Mitrani, 1988; Mori *et al.*, 2014). Evidence points to moonlight avoidance by prey species developing in the late Miocene era to avoid predators (Barthelmess, 2006).

There is currently little research regarding what effect the lunar cycle has on activity levels in captive Cape Porcupines. Natural biological rhythms and diel cycles are prone to alteration in captivity due to factors such as artificial light, resource availability, visitor presence, schedules and unnatural weather (Sherwen and Hemsworth, 2019). Given the frequency of porcupines in captivity, research into the day-to-day effects of the lunar cycle on the species on top of these factors could provide a baseline for other nocturnal species and change the care captive collections offer, potentially bettering their welfare state (Rose and Riley, 2019).

The research project investigated what effect the lunar cycle has on the nocturnal behaviour of captive Cape Porcupines. This study could benefit Reaseheath Mini Zoo by providing understanding and reasoning behind specific behaviours seen by their porcupines during the lunar cycle. This knowledge will hopefully allow keepers to offer a better standard of care toward the porcupines, potentially causing a more positive welfare state. As a result, the zoo may want to incorporate shaded areas into the enclosure to encourage natural behaviours and outdoor usage. Hypothetically, this could reduce any unnecessary believed predatory stress to the porcupines. However, the zoo may also want to harness predatory avoidance behaviours to encourage environmental challenge, competency and agency (Clark, 2018).

The hypothesis was that the amount of moonlight displayed at each lunar phase would affect the types of behaviours performed by the porcupines. When there are higher amounts of moonlight (full moon), the

porcupines may show a higher frequency of behaviours associated with predator avoidance and stress. When moonlight is at its lowest (new moon), the porcupines may show more feeding and movement behaviours due to the lack of visibility, reducing the motivation to display predator avoidance.

Methodology

The study observed behaviour overnight, utilising camera traps to capture footage of those displayed (Fleming *et al.*, 2014; O'Connell *et al.*, 2011). The method reduced any impacts a human presence may cause on the study and any potential stressors a physical presence may have on the subjects. Being captive, nocturnal individuals, the porcupines may become distressed due to being unused to human exposure during their routine waking hours. Between November 2022 and March 2023 (to ensure recordings covered two lunar cycles), data collection occurred over three nights surrounding and including the peak of each lunar phase, between 7 p.m. and 7 a.m. Behaviours were recorded at intervals of 30 seconds, applying instantaneous scan sampling (Gilby *et al.*, 2010). Each display of behaviours occurring upon the 30-second intervals was tallied and totalled every night for each behaviour.

Because Reaseheath Mini Zoo was within the University Centre Reaseheath (UCR) campus grounds (Reaseheath, Nantwich, CW5 6DF) and has previously facilitated UCR research projects, it was a practical study site. Given that no facilities within a feasible distance housed Cape Porcupines, the Reaseheath Mini Zoo population was selected. Data collection occurred within their usual indoor and outdoor enclosures at Reaseheath Mini Zoo. The subjects have constant, overnight access to both indoor and outdoor enclosures. The outdoors incorporates a naturalistic design, featuring many logs and natural wooden structures. The indoor features a 20-25°C infrared heat lamp and is the most common resting place of the subjects (Personal Communication, 2022).

The subjects for the study were the three Cape Porcupines at Reaseheath Mini Zoo. Individual physical characteristics provided by ZIMS records and personal communication identified the porcupines. The subjects consisted of subject one, an adult female (14 years old), subject two, an adult female (12 years old), and subject three, a castrated adult male (8 years old). Behaviours were distinguished from a well-referenced ethogram of the researcher's creation using information from other behavioural studies on the species (see appendix A1) (Coppola and Felicioli, 2021; Giné *et al.*, 2011; Mukherjee *et al.*, 2018; Roze, 2014). To identify each lunar phase, the mobile application (app) MoonX was used (Yarotski, 2022).

The dependent variable, the number of behaviours displayed, was measured continuously. The independent variable, the different lunar cycles, was categorical. Therefore, linear regression tests run on RStudio (Version 1.2.1335) were chosen for data analysis (Horton and Kleinman, 2015; RStudio Team, 2019). This test determined if a relationship between the lunar cycle and the frequency of behaviours was present. Data from each subject underwent individual examination to determine if a relationship occurred. Group data analysis also took place to determine an overall effect and evidence of a relationship. As a linear regression test only uses numerical data, the lunar phases were coded as New Moon = 1, First Quarter = 2, Full Moon = 3, Third Quarter = 4 (Horton and Kleinman, 2015).

The study subjects, the study site, the collection timeframe, the method of identifying/measuring Cape Porcupine behaviours, data intervals and the location of the camera traps were all controlled to ensure the study's validity and limit any influence.

Results

Individual descriptive statistics

A Shapiro-Wilk test, separately conducted, was done to determine each distribution, Subject One (P= 0.0221), Subject Two (P= 0.033), and Subject Three (P= 0.0288). The median and interquartile range were chosen as descriptive statistics as the data was non-parametric.

Group descriptive statistics

A Shapiro-Wilk test was conducted on the total count of all subject's data to determine distribution (P= 0.210). The median and interquartile range were chosen as descriptive statistics as the data was non-parametric.

Individual data analysis

The analysis took place on two months of data on the individual subjects. Evidence of difference was visible from the raw data between the frequency of specific behaviours and specific lunar phases. Graph 1 illustrates that Subject One displayed the grooming (GR) behaviour most frequently on full moons (3) when moonlight was brightest (see Figure 1). Although, as grooming (GR) displays were displayed on new moons (1) more than that displayed on first quarter (2) and third quarter phases (4), the data suggests that luminosity increase did not coincide with the behaviour increase. It instead suggests that behaviour increase not only, occurred when luminosity peaked, but also when it troughed. Graph 2 established a positive association between an increase in luminosity, and the behaviour allo-grooming (AG) displayed by Subject Two increased (See Figure 2). However, as moonlight is the same during first (1) and third quarter (4) phases, the effect on behaviour could have the same effect. Graph 3 indicates how Subject Three demonstrated a high occurrence of the behaviour immobility (IM) on full moons (See Figure 3). The data suggests that for subject three, the increase in immobility (IM) occurred at both maximum and minimum lunar luminosity levels.

General linear models, created using stepwise deletion, determined the most affected behaviours in individual subjects (see Table 1). However, the models found no significant relationship between the lunar phases and the behaviours. The most significant behaviours affected in Subject One were foraging (FG) (Z= 0.643, P= 0.521), socialising (S) (Z= 0.643, P= 0.620) and aggression (AR)= 0.431). The most significant behaviours affected in Subject Two were immobility (IM) (Z= 1.283, P= 0.199), socialising (S) (Z= -1.007, P= 0.314) and flashing (FL) (Z= -0.440, P= 0.660). The most significant behaviours affected in Subject Three were eating (ET) (Z= 706, P= 0.480), aggression (AG) (Z= 0.319, P= 750) and laying down (LD) (Z= 0.483, P= 0.630).

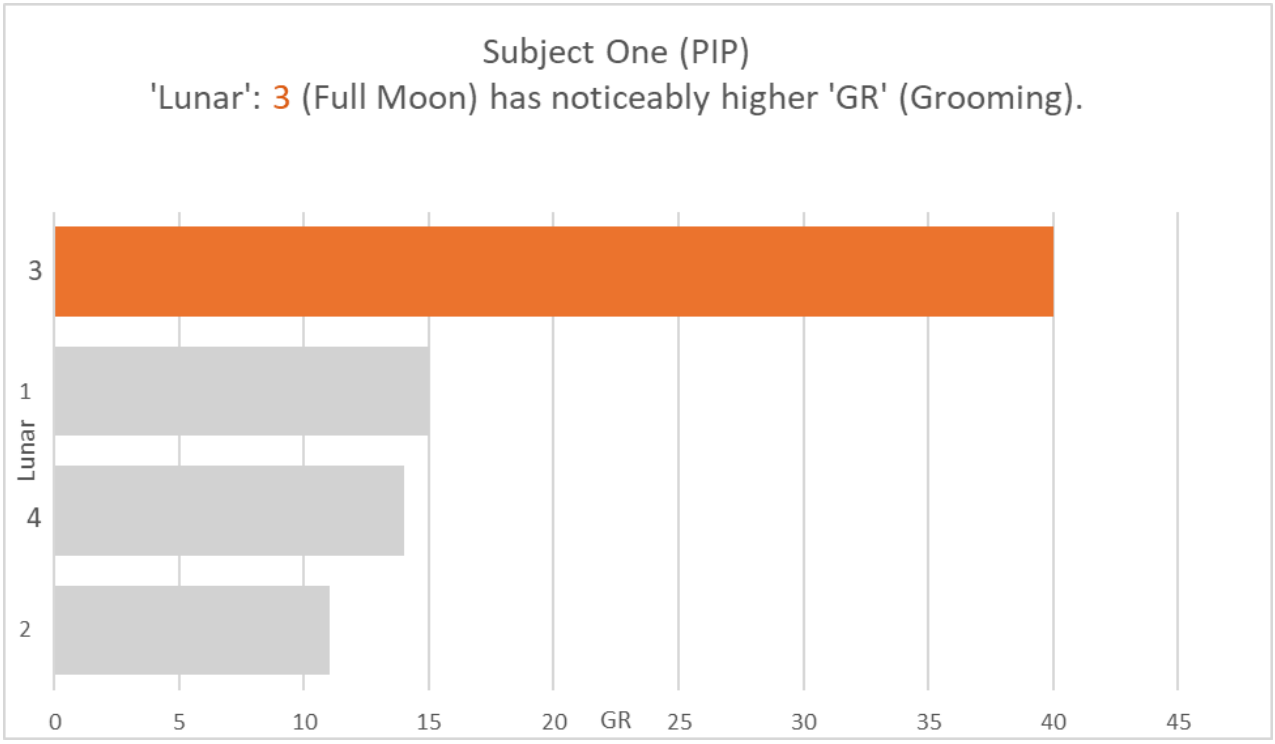

Figure 1: A graph displaying the frequency of 'grooming' (GR) in Subject One at different Lunar phases

Graph 1. The behaviour GR (Grooming) had a total count of 40 during Lunar 4 (Full Moon) and a count of 15 during Lunar 1 (New moon), indicating an association between the behaviour frequency and the moonlight produced during these cycles in Subject One. The behaviour had a total count of 14 during Lunar 4 (Third Quarter), and 11 during Lunar 2 (First Quarter).

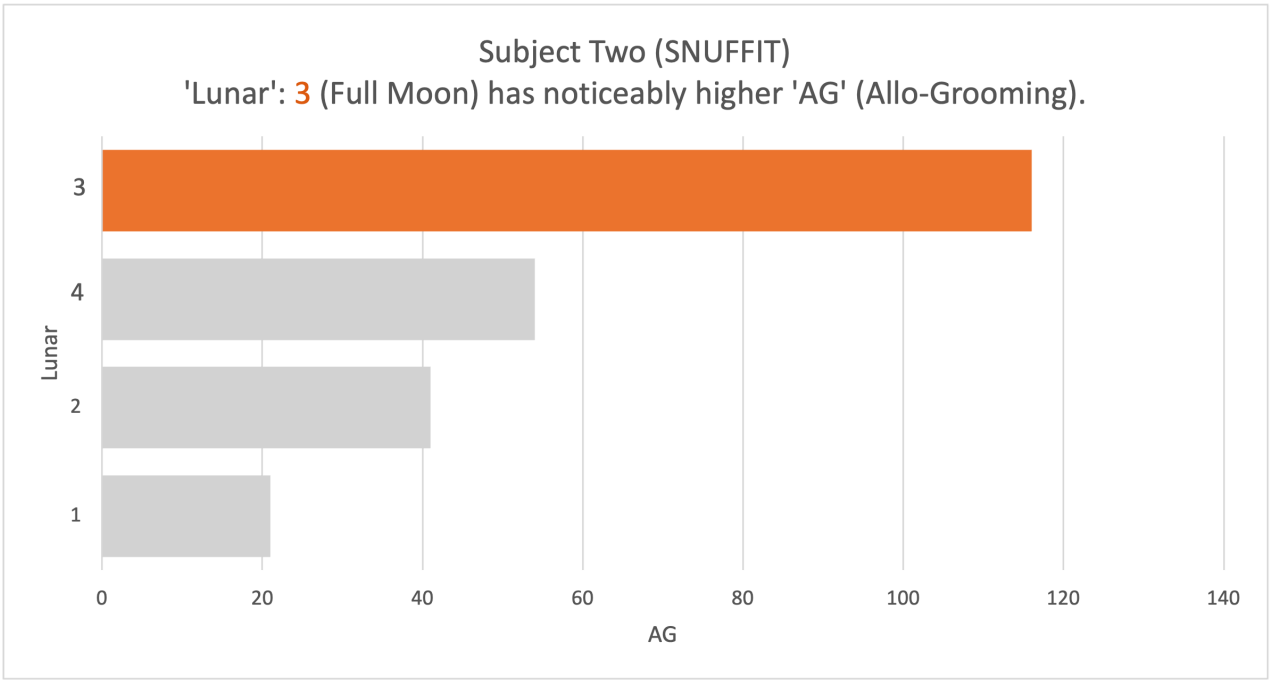

Figure 2: A graph displaying the frequency of 'allo-grooming' (AG) in Subject Two at different Lunar phases

Graph 2. The behaviour AG (allo-grooming) had a total count of 116 during the Lunar 3 (Full Moon). This count reduced as the luminosity of each phase decreased (4 = 54, 1 = 21), indicating a positive association between the frequency of the behaviour and an increase in moonlight in Subject Two.

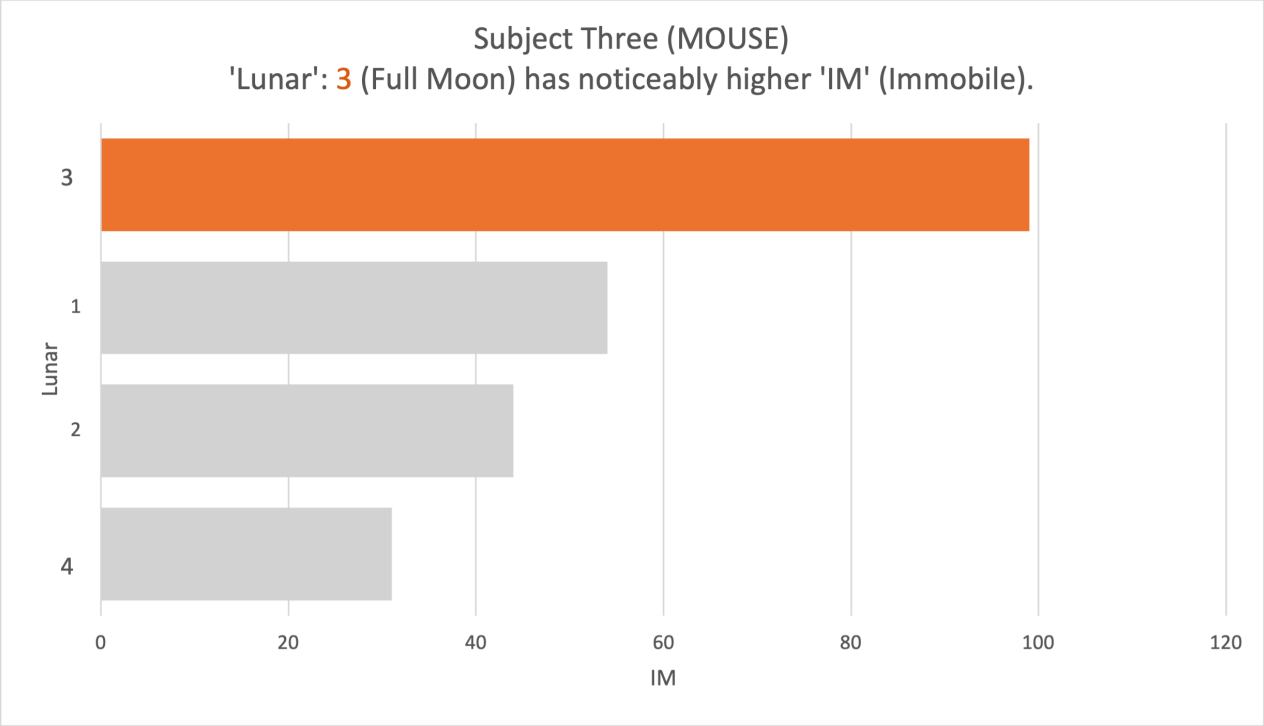

Figure 3: A graph displaying the frequency of 'immobile' (IM) in Subject Three at different Lunar phases

Graph 3. The behaviour IM (Immobile) had a total count of 99 during Lunar 3 (Full Moon) and a count of 54 during Lunar 1 (New Moon), indicating an association between the behaviour frequency and the moonlight produced during these cycles in Subject Three. The behaviour had a total count of 31 during Lunar 4 (Third Quarter), and 44 during Lunar 2 (First Quarter).

	Predictor	Estimate	Standard Error	Z-value	P-value
Subject One (PIP)	Intercept	1.003	0.255	3.932	8.41e-05
	FG	0.013	0.021	0.643	0.521
	S	-0.010	0.020	-0.496	0.620
	AR	-0.103	0.126	-0.818	0.431
Subject Two (SNUFFIT)	Intercept	0.965	0.238	4.046	5.2e-05
	IM	0.023	0.018	1.283	0.199
	S	-0.037	0.037	-1.007	0.314
	FL	-0.025	0.056	-0.440	0.660
Subject Three (MOUSE)	Intercept	0.778	0.230	3.370	0.001
	ET	0.006	0.008	0.706	0.480
	AG	0.001	0.004	0.319	0.750
	LD	0.004	0.008	0.483	0.630

Table 1: Final quasipoisson general linear model predictors for each subject, using independent monthly lunar variables

Group data analysis

The analysis took place on two months of data on the collective sum of all subjects. Evidence of difference was visible from the raw data between the frequency of specific behaviours and specific lunar phases. Graph 4 shows a coinciding increase in the frequency of the behaviour AG as the amount of moonlight increased through the lunar phases (see Figure 4).

A general linear model, created using stepwise deletion, determined the most frequent behaviours displayed by the collective sum of all subjects (see Table 2). However, the model found no significant relationship between the lunar phases and the behaviours. The most significant behaviours affected for the group were socialising (S) (Z= -0.774, P= 0.439), immobility (IM) (Z= 1.033, P= 0.302), and foraging (FG) (Z= 0.350, P= 0.726).

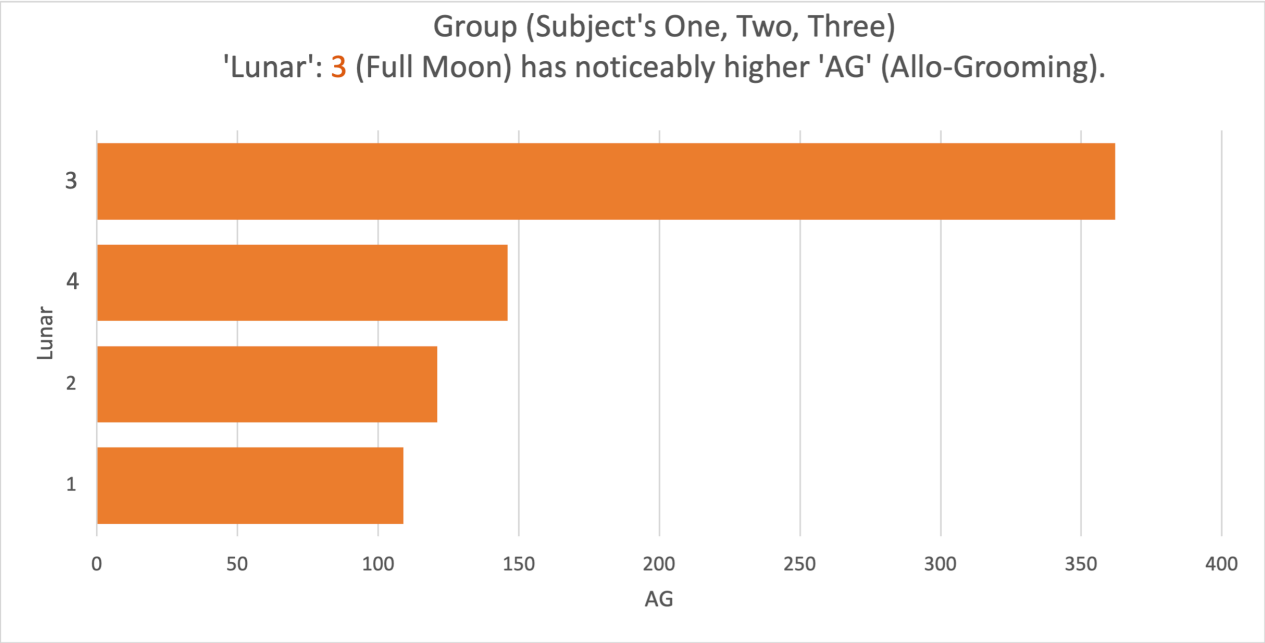

Figure 3: A graph displaying the frequency of 'allo-grooming' in the group at different lunar phases

Graph 4. The behaviour AG (allo-grooming) had a total count of 362 during the Lunar 3 (Full Moon). This count reduced as the luminosity of the phases decreased (1 = 109), indicating a positive association between the frequency of the behaviour and an increase in moonlight in all subjects. As Lunar 2 and 4 produce the same luminosity, behaviour may be affected similarly, explaining the lack of variation between the two.

	Coefficient	Estimate	Standard Error	Z-value	P-value
Group (All Subjects)	Intercept	0.768	0.286	2.681	0.007
	S	-0.008	0.011	-0.774	0.439
	IM	0.007	0.006	1.033	0.302
	FG	0.002	0.007	0.350	0.726

Table 2: Final quasipoisson general linear model predictors for each subject, using independent monthly lunar variables

Discussion

A difference in the frequency of specific behaviours regarding particular lunar cycles was evident from the data collected. As moonlight levels intensified across the lunar cycle, an increase in resting and maintenance behaviours was observed. The behaviours grooming (GR) (Subject One), allo-grooming (AG) (Subject Two), and immobility (IM) (Subject Three) were most associated with the full moon lunar phase when moonlight was highest. Similarly, the group showed an association between the behaviour of AG and the full moon. Maintenance behaviours are performed by rodents in an evolved sequence which is prone to alteration by external and internal stimuli such as stressors and neurological differences (Smolinsky *et al.*, 2009). For many mammalian species, maintenance behaviours are perceived as stereotypical in captive animals, indicating a negative welfare state (Smolinsky *et al.*, 2009; Pomerantz *et al.*, 2013). However, contrasting studies suggest that associating high stress with increased grooming behaviours is an oversimplification due to the behaviours' complexity (Kalueff and Tuohimaa, 2005). Even so, rodents experience increased maintenance behaviours at high or low-stress levels (Kalueff and Tuohimaa, 2004; Moyaho and Valencia, 2002). The two extremes differ as stress-induced grooming occurs in short bursts, at rapid rates, and is often incomplete and interrupted (Kalueff and Tuohimaa, 2005; Smolinsky *et al.*, 2009). Placing this information into context regarding the results, as the subjects are captive individuals, the increase in maintenance behaviours is interpreted as a stereotypical stress response (Kalueff *et al.*, 2016; Smolinsky *et al.*, 2009). However, this does not have to indicate a negative welfare state in the subjects.

The heightened presence of the behaviour IM, a resting behaviour, suggests that these behaviours are an evolved anti-predatory response (Barthelmess, 2006). However, the analysis results suggest no significant relationship between the lunar cycle and the behaviours. The estimates and z-values from the individual GLMs suggest a positive average change in the resting and maintenance behaviours as moonlight increased (see Table 1). The group GLM again implied a positive average change in the behaviours of IM and FG as moonlight increased (see Table 2). These positive changes can also be interpreted as an anti-predatory response to the rising exposure (Barthelmess, 2006). However, the increase in feeding behaviours indicates a captive influence (Sherwen and Hemsworth, 2019). Living in captivity can affect natural rhythms and diel cycles, which could cause the porcupines to unnaturally increase their foraging and eating levels when moonlight is high due to food being available (Berger, 2011; Giné *et al.*, 2011).

The data and interpretations strengthen the hypothesis that the amount of moonlight displayed at each lunar phase would affect the types of behaviours performed by the porcupines. When there are higher amounts of moonlight (full moon), the porcupines may show a higher frequency of behaviours associated with predator avoidance and stress. When moonlight is at its lowest (new moon), the porcupines may show more feeding and movement behaviours due to the lack of visibility, reducing the motivation to display predator avoidance. However, the lack of significance suggested by the GLMs contradicts the hypothesis as they imply the amounts of moonlight had little to no effect on the porcupine's behaviours. The data from Subjects One and Three suggest that the two extremes of moonlight caused the most frequent behaviour displays.

This point supports the hypothesis due to the types of behaviour, GR and IM, as they are associated with predator avoidance and show moonlight has some effect on the behaviours (Barthelmess, 2006; Kalueff *et al.*, 2016; Smolinsky *et al.*, 2009).However, it does dispute the hypothesis as although an interpreted anti-predatory effect occurs, behaviours are not limited to high moonlight phases.

Considering previous field studies on the effects of moonlight on other hystrix species, the results share similar findings. These studies on the effects of moonlight on porcupines found a significant relationship between moonlight and activity levels, with findings discussing how activity levels were highest when moonlight exposure was reduced (Alkon and Mitrani, 1988, Mori *et al.*, 2014). A study researched the impact of seasonality on activity levels (Alkon and Mitrani, 1988). Regardless of the lunar phase, this study found activity levels were higher during the winter as the weather reduced moonlight exposure (Alkon and Mitrani, 1988). However, other studies found a trigger-like relationship between the lunar phases and porcupine activity budgets, as even when invisible, full moons hindered activity levels and reduced behaviours (Mori *et al.*, 2014). The results from this study uphold the field findings as, although significance was not found, from the GLMs, the increase in maintenance and resting behaviours upon full moons observed from the raw data backs up their hypothesis.

These findings could prove significant by providing a baseline for studies on other nocturnal species. Nocturnal diel cycles exist in most mammalian species, and moonlight can raise predation risk for these species, not limited to the hystrix genera (Prugh and Golden, 2014).

The evolutionary traits and behaviours associated with nocturnal diel cycles can translate into captivity, where artificial factors can cause an unnatural response (Sherwen and Hemsworth, 2019).

Although, field evidence of porcupine species displaying 'sunbathing' behaviours in the wild during diurnal hours contradicts this point (Coppola *et al.*, 2019). If exhibited in captivity, arguments would point to the behaviour being a natural physiological response from the porcupine (Coppola *et al.*, 2019).

Studies into the effects of moonlight on prey have previously neglected the impact on foraging efficiency, which has the potential to translate into captive individuals (Prugh and Golden, 2014; Sherwen and Hemsworth, 2019). Foraging was suppressed in rodent species when higher levels of moonlight were present to the point where it reached similar levels to that of a predatory presence (Prugh and Golden, 2014). In captivity, this could cause negative welfare implications encouraging stereotypical behaviours and increased states of stress (Rose and Riley, 2019). As visitors have more enjoyable experiences when animals are present, some studies have recommended using environmental enrichment to encourage diurnal activity in nocturnal species (Fernandez *et al.*, 2009; Margulis *et al.*, 2003). The presence of visitors could be mistaken by nocturnal species as a predatory presence, causing foraging suppression as a predator avoidance reaction, leading to a potential negative welfare state (Fernandez *et al.*, 2009; Rose and Riley, 2019).

As an implication of the results, Reaseheath Mini Zoo may wish to incorporate changes to their husbandry routines and enclosure design. The insight from this study can provide the zoo with context to specific behaviours observed in the group that can justify changes.

The zoo may wish to incorporate shaded areas into the outdoor enclosure to reduce stress-induced maintenance behaviours and better the subject's welfare (Rose and Riley, 2019; Smolinsky *et al.*, 2009). The porcupines can benefit from this as the reduction in moonlight exposure on the third quarter and whole moon cycles and limiting unnecessary predator avoidance cues (Kalueff and Tuohimaa, 2005; Mori *et al.*, 2014). A potential increase in outdoor enclosure usage may result from these shaded additions, possibly bettering welfare and reducing hostile interactions between con specifics (Nogueira *et al.*, 2004).

Providing shaded areas can also benefit the subjects during daytime hours. As captivity can change biological cycles and circadian rhythms due to husbandry and feeding routines, it is common to see captive porcupines with more cathemeral diel cycles (Corsini *et al.*, 1995; Hagen *et al.*, 2020; Ramírez-Chaves *et al.*, 2020;

Sherwen and Hemsworth, 2019). Due to their retained evolutionary traits for nocturnal life, this sunlight exposure can potentially impact health and welfare (Rose and Riley, 2019; Torres and Clarke, 2018). Shaded areas can relieve pressures on their nocturnal traits while not restricting their activity levels and benefit visitor experiences (Fernandez *et al.*, 2009). Limiting husbandry routines to early or late hours can reduce any disturbance caused to the diel cycles of the porcupine and limit interference with important resting behaviours (Gandia, 2023).

However, the biological perception and response to the lunar cycle are not solely related to luminosity levels. Studies hypothesise that because geomagnetic activity fluctuates around specific lunar phases, animals sensitive to this could display changes in behaviour and activity levels in response (Bevington, 2015; Chakraborty, 2020; Nishimura and Fukushima, 2009).

The effects of climate change could affect lunar perception – for example, changes in temperature, humidity and weather that may coincide around lunar phases could lead to variations in the behaviours of nocturnal mammals as a response (Camuffo, 2001; Chakraborty, 2020; Rode-Margono and Nekaris, 2014).

To exemplify, satellite technology confirmed the moon impacts global temperatures, with warmth coinciding with the full moon (Balling Jr and Cerveny, 1995). Behaviour studies indicate that the collaboration between temperature and moonlight influenced the observed nocturnal activity pattern (Fernandez-Duque, 2003).

Reaseheath Mini Zoo may wish to harness predatory avoidance behaviours to encourage environmental challenge, competency and agency (Clark, 2018). Promoting predatory avoidance allows the porcupines to acquire a repertoire of natural cognitive skills they can use when faced with a challenge (Clark, 2017). This promotion provides the porcupines with a more wild-like, enriching experience of captivity that can limit boredom and reduce the capacity for stereotypical behaviour development (Clark, 2017).

To promote predatory avoidance, Reaseheath Mini Zoo could shift the porcupine's feeding schedule to later hours to limit disturbing diurnal resting behaviours (Savenije *et al.*, 2010). Automatic scatter feeders timed for these hours can be used to achieve this (Andrews and Ha, 2014; Law and Reid, 2010). These devices can increase feeding and moving behaviours by encouraging foraging and increased enclosure usage (Andrews and Ha, 2014). They can also reduce contra-freeloading as the devices are often portable and can be moved to separate locations and set to unpredictable times each night (Clark, 2017).

Opposed to this, the zoo could change feeding times to earlier/later in the day to reduce potential disturbances to the diel cycles and resting behaviours (Savenije *et al.*, 2010).

Utilising camera traps for this study was beneficial as it allowed the collection of a sizeable amount of data and minimised any harm to the researcher and the subjects. Camera traps limited hypothetical stressors that may have become apparent from an unknown physical presence. This method also reduced the collection of influenced data human presence could have caused due to the unfamiliarity of human company at late hours. Overall, this method reduced anthropogenic impacts that may have negatively affected animal welfare or manipulated the data (Caravaggi *et al.*, 2017). The camera traps also covered multiple areas of the enclosure to get the best possible view of the behaviours displayed at the chosen intervals (Caravaggi *et al.*, 2017). The camera traps also reduced human error from missing collection intervals and refined the study because of the pause and replay functions. In-person behaviour observation may have led to a lack of data in the study due to distractions. However, technical problems did occur due to weather and limited power sources.

The camera traps ran on 12 AA alkaline batteries, prone to failure during cold weather (Palacín and de Guibert, 2016). As the collection period fell between November 2022 and March 2023, the weather was often colder and unpredictable. A solution to this would be an alternative power source like Lithium-Ion batteries that fare better in colder environments (Dagger *et al.*, 2017).

Significance in the relationship between the lunar cycles and nocturnal porcupine behaviours had a higher probability of being found from the GLMs if the data sets were larger (Bakeman and Quera, 2012).

Increasing data collection time frames, covering more lunar cycles, collecting data from multiple collections, utilising more camera traps to capture more angles and limiting the frequency of invisible behaviours recorded could correct this issue. Conducting the study over multiple seasons, particularly over summer, could provide a better range of data because extreme weather such as rain and snow can hinder porcupine activity and increase resting behaviours from limited outdoor exposure (Alkon and Mitrani, 1988).

Conclusions

Given the frequency of porcupine species in UK zoos, the findings of this study can provide insight into how alterations to husbandry and animal care can impact the effect of lunar cycles. Research on the behavioural impacts of lunar cycles on their porcupines can allow Reaseheath Mini Zoo to encourage a better welfare state in their prickle (collective noun for porcupines). By integrating suggestions from this study, collections may increase the probability of their porcupine populations adopting a positive welfare state. However, as it is not unusual for diel cycles to change in captivity, it can be argued that because zoo visitors have a better experience when animals are visible, encouraging a more cathemeral diel cycle in Cape Porcupines should be fostered as is likely to occur otherwise. Conversely, this can change how porcupines respond to environmental cues like the lunar cycle and impact how they interact with their environment. By understanding the findings from this study, collections can adapt captive life for their porcupines to encourage natural cued responses. The take-home message from this study is that behavioural change was visible in the subjects concerning the amount of moonlight produced by the lunar phases. This behavioural change can cause positive and negative welfare implications on the affective state of the porcupines on an individual and group scale. Under the Zoo Licencing Act (1981), UK zoological collections must abide by the provisions stated in the Secretary of State's Standards of Modern Zoo Practice (2012)- 'SSSZMP', the fourth provision being supplying the opportunity for natural behaviours. As the evidence points to predatory avoidance being an evolutionary trait, collections can meet this provision using the findings and suggestions from this study. Promoting natural diel cycles can also be done to meet this provision and ensure that the animal's welfare requirements meet the standard of the SSSMZP (2012).

Investigation into additional factors that may affect the behaviour and activity budgets of Cape Porcupine would further this study. As data collection methods became impacted by weather, further developments could pair together how different weather affects the behaviours of captive Cape Porcupines regarding the lunar cycle. Studies on the effect of seasonality have touched on the subject concerning wild Indian crested porcupines (*Hystrix indica*) in the field (Alkon and Mitrani, 1988). Although done on a similar topic and species, development could benefit from moving in a more focused direction regarding the effect of weather and lunar phases.

Analysis of the before and aftereffects and value of incorporating shaded areas into enclosure design on nocturnal mammals in captivity would be a good direction for this study to expand.

From the study, a potential relationship between the lunar cycle and enclosure usage arose. The subjects at Reaseheath Mini Zoo have ad-libitum access to both an indoor and outdoor chamber, where an impact on preference may have been because of moonlight exposure. Based on evidence regarding the porcupine's anti-predatory responses, it is likely that, on brighter lunar phases, indoor enclosures are preferred (Mori *et al.*, 2014). Development on this can come from the results of this study because the behaviours with the highest growth regarding risen moonlight levels were those of resting and maintenance. These behaviours could have a significant association with the indoor enclosure as this is the favoured resting site of the subjects (Personal Communication, 2022). However, due to the variation in UK weather, it would need to be considered as a potential influence on enclosure preference.

Another question spurred by the research was the effect of the lunar cycle on sex in Cape Porcupines. As the subject did not consist of an equally split group of males and females, with there being two females and one male, who was castrated, this was not a considered factor. However, from the results, Subject Three (male) showed a significant increase in resting behaviours when moonlight was brightest. However, in Subject One (female) and Subject Two (female), a rise was seen in maintenance behaviours. Observations on hystrix reproductive behaviours have previously occurred. However, context and insight focus on wild individuals and habitat effects (Coppola and Felicioli, 2021; Van Aarde, 1987). Further research on this factor can benefit captive breeding programmes as they may find a higher rate of breeding success when lunar cycle activity budgets are understood.

The study lacked finding an overall relationship between lunar cycles and Cape Porcupine behaviours due to the limited sample size. Therefore, further research on the question would provide a clear outlook on the effect on the whole species rather than one collection. The importance of future research for the species is that it can further the interest in finding the relationship in other captive hystrix species, captive rodents or captive nocturnal animals. Collections can then use this information to ensure that welfare provisions in captivity can be specialised to suit the needs of these categories, possibly bettering their welfare states.

Appendix 1

Ethogram of Cape Porcupine behaviours

Feeding behaviours		
- Eating	ET	Chewing, swallowing, consuming food item (Mukherjee *et al.*, 2018).
- Foraging	FG	Browsing/searching for food items/water (Giné *et al.*, 2011).
- Drinking	DR	Consuming water.
Resting behaviours		
- Immobile position	IM	Standing still on four limbs for more than 2 seconds.
- Laying Down	LD	Laying down on ground but awake. Front limbs extended in front of face and hind limbs bent at side of body (Mukherjee *et al.*, 2018).
- Sleeping	SL	Unconscious, eyes closed, no movement laying down on ground (Giné *et al.*, 2011).

Moving behaviours		
- Locomotion	LM	Moving around the enclosure at a steady pace with no food involved. Moving all four limbs individually.
- Running	RN	Moving around the enclosure at a quick pace with no food involved. Moving all four limbs individually.
- Social interaction	S	Two or more con specifics interacting in close contact with one another for more than 2 seconds (Felicioli *et al.*, 1997).
- Aggression	AR	Using quills, teeth, body force to physically harm a con-specific or human (Roze, 2014; Mori and Ferrari., 2021).
- Digging	DG	Breaking up of dirt using claws and front limbs (Mukherjee *et al.*, 2018).
- Object Play	OP	Interaction with an inanimate object for more than 2 seconds, may or may not involve a con-specific (Mukherjee *et al.*, 2018).
- Con-specific Play	CP	Interaction with a con-specific e.g., leaping on one another. Performed in a positive manner for longer than 5 seconds (Mukherjee *et al.*, 2018).
Maintenance behaviours		
- Grooming	GR	Moving claws front to back in a 'combing' motion to clean fur.
- Allo-grooming	AG	Mutual grooming involving licking the tail, licking the head or the neck of another con-specific (Felicioli *et al.*, 1997).
- Urinating/Defecating	UD	Release of urine/faeces.
Communication		
- Rattling	RT	Vibrating tails/rattle quills to produce a warning sound.
- Flashing Quills/Mane	FL	Flaring quills and raising mane to increase body size (Roze, 2014).
- Vocalisations	VO	Creation of sound from individual/s (Roze, 2014).
Missing behaviours		
- Invisible	IN	Individuals not visible/behaviour not captured.
Other	O	Observed behaviours not listed within this ethogram.

Note: A Cape Porcupine Ethogram describing the behaviours potentially seen in the study. Information sourced from Coppola and Felicioli, 2021; Giné *et al.*, 2011; Mukherjee *et al.*, 2018; Roze, 2014.

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Glossary

Abiotic environmental cue: Non-living factors that trigger changes in organisms and ecosystems.

Allo-grooming: Mutual grooming involving licking the tail, licking the head or the neck of another con specific (Felicioli et al., 1997).

Cathemeral: Activity pattern where an organism is active at anytime of day or night, activity is based on environmental settings.

Circadian: Biological processes that occur over a 24-hour period.

Circannual: A biological process that recurs annually.

Crepuscular: Activity pattern where an organism is active during dusk and dawn.

Diurnal: Activity pattern where an organism is active during the day.

Ectothermic: When an organism is reliant on external sources of heat to maintain body temperature.

Endothermic: When an organism can produce heat internally.

Nocturnality: Activity pattern where an organism is active during the night.

Non-nocturnal diel cycles: Any activity patterns displayed by an organism outside of night.

Non-Parametric: A form of statistical analysis that makes marginal assumptions about the underlying distribution of the data being analyzed.

Photopigment evolution: Unpredictable pigments that experience a chemical change when they absorb light. In different organisms, these pigments have evolved to react differently to light in reaction to different diel cycles.

Stepwise deletion: Stepwise deletion or regression removes the weakest correlated variable.

Trophic co-evolution of behaviours: When the feeding behaviours of two different organisms evolve in response to one another.

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A Comparative Study of Photon Radiation-Shielding Properties of Different Glass Types for Use in Health Facilities

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Abstract

The usage of X-ray generating devices and gamma-ray sources such as 60Co and 137Cs for medical diagnostic and therapeutic applications has increased globally. However, exposure to radiation from these sources can cause detrimental effects on biological tissues. Thus, to optimise radiation safety, effective radiation shields are required. This study used the photon shielding and dosimetry (PSD) software to simulate and compare the photon shielding properties of phosphate, bismuthate, tellurite, silicate and borate glass for use in medical facilities. The parameters investigated included mass attenuation coefficient (MAC), linear attenuation coefficient (LAC), half-value layer (HVL), mean-free path (MFP), and effective atomic number (Z_{eff}). The results showed that bismuthate glass had the highest MAC and LAC values followed by tellurite, silicate, phosphate and borate glass respectively. It was also found that bismuthate glass had the lowest HVL and MFP values followed by tellurite, silicate, phosphate and borate glass. Since materials with high MAC and LAC and low HVL and MFP are associated with higher photon stoppage powers, bismuthate glass are better photon shielding materials compared to the rest of the glass examined in this study. Conversely, borate glass presented the least shielding potential compared to phosphate, silicate and tellurite glass.

Keywords: Radiation attenuation coefficients, Phy-X/PSD software, radiation-shielding parameters, radiation effects, bismuthate glass shields, borate glass shields

Introduction

Humans occasionally encounter radiation in the field of medicine during radiology, cardiology and radiotherapy procedures (Ruengsri, 2014). However, excessive exposure to ionising radiation may result in temporal or permanent tissue damage, acute radiation syndrome, and enhanced cancer risks (Dowlath *et al.*, 2021). This can be even worse for radiation workers as they can get exposed to enhanced radiation levels or accumulate higher doses over time due to the nature of their jobs. One of the measures of radiation protection that must be put in place to safeguard radiation workers (staff) from excessive exposure to ionising radiation is the use of effective radiation shields. A radiation shield absorbs the incoming photons and reduces the radiation intensity to safe levels, thereby protecting humans. Radiation shields vary from metal sheets to concrete and glass (Mhareb *et al.*, 2020). Simple lead has historically been the most common photon radiation shield because of its high density, making it highly effective at attenuating photons. However, due to its toxic nature, there is restricted use of it in medical treatment facilities (El-Mallawany *et al.*, 2018). Therefore, environmentally friendly substitutes for lead that are just as effective have been studied by many researchers to reduce lead toxicity. Concrete is a great candidate for this because of its low cost, simple manufacturing, and wide range of composition (Saddeek *et al.*, 2020). However, concrete is prone to cracking and water loss over time. This has led researchers to seek alternative materials.

Radiation-shielding glass come with the additional advantage of being transparent and not cracking, as well as providing the same benefits as concrete (Yasmin *et al.*, 2018). Transparency is important for viewing activities in the adjacent room while carrying out radiological procedures and is also applied in non-medical situations (Almatari *et al.*, 2019). Radiology uses average energies of 20 keV (dental), 30 keV (mammography), 40 keV (general) and 60 keV (computed tomography), respectively. Since these energies are the typical energy levels of photons used in the medical field, the glass investigated in this study were examined under these energy ranges (Abouhaswa *et al.*, 2021). The Phy-X/PSD software was used to determine the radiation-shielding properties such as mass attenuation coefficient (MAC), linear attenuation coefficient (LAC), half-value layer (HVL), effective atomic number (Z_{eff}), and the mean-free path (MFP) of the borate, tellurite, silicate, phosphate and bismuthate glass. These parameters are basic quantities often used for analysing the penetration and the energy deposition by photons. It is worth noting that the quality of data produced by modern simulation codes is limited to the quality of the embedded data libraries. The MAC describes the fraction or amount of incident photons absorbed in a unit mass of an absorber material. MAC is a useful parameter for finding the radiation leaving the materials.

On the other hand, LAC describes the attenuation of radiation per unit length of a material. In simple terms, LAC is the probability of interaction between radiation and the material per distance (Sayyed *et al.*, 2021). It characterises how easily a photon beam can penetrate a material volume. HVL is the thickness of a material required to reduce the intensity of a photon beam to half of its original value. The HVL values directly depend on the composition, density and structural arrangements of the constituents of a material. It is merely a proxy measure of the penetrating power of a photon beam, also known as beam quality (Waly *et al.*, 2018a). A lower HVL represents a better radiation-shielding property of a material. In photon shielding, these parameters are key in describing the ability of a photon beam to interact with and deposit its energy in the shielding material. The effective atomic number (Z_{eff}) represents the total number of electrons surrounding the nucleus of an atom. It comprises a metal atom's electrons and the bonding electrons from the surrounding electron-donating atoms and molecules, and it is closely related to the electron density, expressed in the number of electrons per unit mass (Manohara *et al.*, 2008). The MFP is the average distance radiation travels in a material before it undergoes another interaction.

Materials

The materials investigated in this study include phosphate, borate, silicate, bismuthate and tellurite glass. The glasses were coded as S1, S2, S3, S4 and S5, respectively as shown in Table 1. Table 1 also contains the chemical formulae, average molecular weight, densities of the glass under examination, and weight fractions of the constituent elements in these glass.

Table 1: Sample codes and their compositions

Code	Sample name	Chemical formula	AMW (g/mol)	Density (g/cm^3)	Weight fraction of elements (%)					
					O	P	B	Si	Bi	Te
S1	Phosphate glass	P_2O_5	141.94	2.39	0.5636	0.4364				
S2	Borate glass	B_2O_3	69.62	2.46	0.6894		0.3106			
S3	Silicate glass	SiO_2	60.08	2.65	0.5326			0.4674		
S4	Bismuthate glass	Bi_2O_3	465.96	8.9	0.1030				0.8970	
S5	Tellurite glass	TeO_4	191.60	6.24	0.3340					0.6660

Methods

Calculation of mass and linear attenuation coefficients

The MAC and LAC (μ) of the different glass types were determined using the Phy-X/PSD simulation software. The Phy-X software is an online simulation software that is used to calculate photon dosimetry and shielding properties of different shielding materials (Hussein *et al.*, 2022). The calculated values of the linear attenuation coefficient were used to determine the HVL and MFP as discussed below.

Calculation of half-value layer

In radiation protection through shielding, the goal is to reduce the intensity of the incident beam as much as possible, even with the smallest material thickness. So, finding a material that can reduce a beam intensity by half within a minimal material depth (i.e. a material with the lowest HVL) is of interest in radiation shielding. In this study, the HVL calculations for the different glass types were done using the equation (Al-Buriahi *et al.*, 2019):

$$\mathrm{HVL} = \frac{\ln 2}{\mu}$$

where μ is the LAC of the glass.

Calculation of effective atomic number

The effective atomic numbers of the different glass types were also determined using the Phy-X/PSD simulation software (Hussein *et al.*, 2022). In Atomic and Nuclear Physics, the atomic number Z (i.e. the number of protons in the nucleus) of an atom is a desired parameter in radiation-shielding design because it exhibits a strong and fundamental relationship with the nature of radiation interactions with that medium. However, for complex media such as compounds and other composite systems, a single atomic number cannot be used as the atomic number of a material composed of several elements. In this case, the effective atomic number, Z_{eff}, is a convenient parameter in radiation-shielding calculations so that the various atomic

numbers in the material have to be weighted differently for the different photon interaction mechanisms with the matter (Manohara *et al.*, 2008).

Calculation of mean-free path

The MFP represents the statistically averaged distance a photon travels before it is absorbed or scattered in target materials. The MFP is an important parameter in radiation-shielding design when determining the thickness or depth of the material that can effectively stop a photon beam. When the thickness of the shielding material is much shorter than the photon's MFP, the photons propagate throughout the device practically without collision – this is the so-called ballistic transport regime (Dragoman and Dragoman, 1999). Mathematically, MFP is inversely proportional to LAC and is defined as (Singh *et al.*, 2018):

$$\mathrm{MFP} = \frac{1}{\mu}$$

Results and discussion

The mass attenuation coefficient

The values of MAC for all the samples under examination were computed with Phy-X/PSD software in the photon energy range between 15 and 15,000 keV. The variations of the MAC values versus the incident photon energies are shown in Figure 1. It can be seen from Figure 1 that MAC values changed with changes in primary photon energies. Here it can be observed that the MAC values generally decreased in the order of S4 > S5 > S1 > S3 > S2. Also, MAC values are seen to decrease with the increasing photon energy. This decrease in MAC values with increased photon energy is due to reduced dominance of photoelectric absorption in the high-energy region (Sayyed *et al.*, 2018). Since MAC is the measure of the fraction of incident photons absorbed per unit mass of a material, the photon energy, and thus photon interaction mechanisms, are crucial in determining the absorption cross-section. At low photon energies, the photoelectric effect is the most dominant interaction mechanism, while at higher energies, Compton scattering becomes predominant. At very high energies, pair production and photonuclear reactions become important. The overall effect is the observed decrease in attenuation with increased energy (Sayyed *et al.*, 2018). This explains why the MAC values of the investigated glass are highest in the low-energy region.

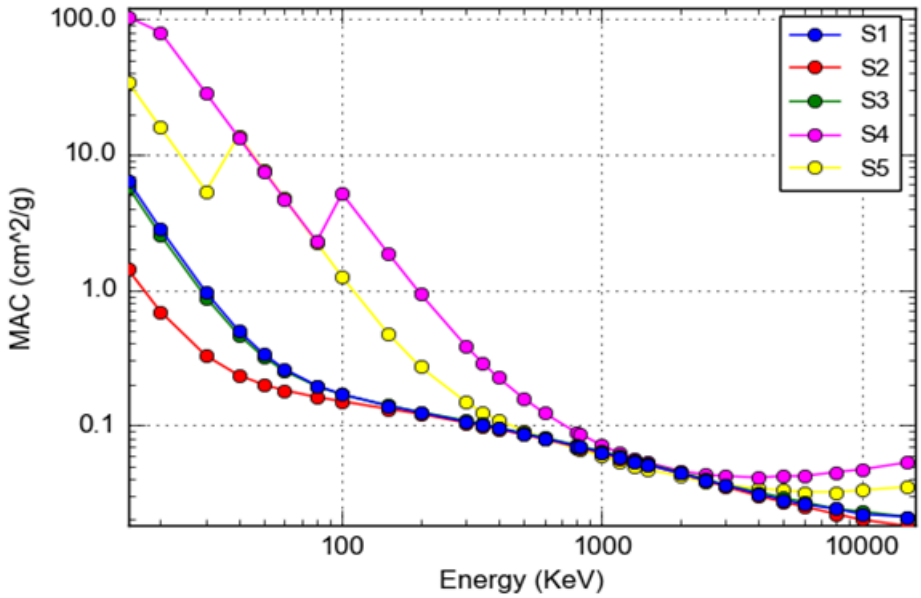

Figure 1: Variations of MAC values with incident photon energy

In the energy range of 15–50 keV, it was observed that the highest MAC values were in the S4 sample and the lowest MAC values were in the S2 sample. This shows that bismuthate glass have better absorption capacity than other comparative glass. It is also observed from **Figure 1** that there is a steep rise in the MAC values for S4 and S5 in the energy ranges of 80 to 100 keV and 20 to 50 keV respectively. This sudden increase is due to the K-shell absorption, which is a sudden increase in photon absorption occurring when the photon energy is just above the binding energy of the innermost electron shell of the atoms interacting with the photons (Bünyamin, 2020). S5 and S4 coincide together between 50 to 80 keV. Figure 1 also shows that the MAC values of all the glass samples coincide at 1500 keV. This is attributed to the Compton scattering effect, the most dominant photon interaction mechanism in this energy range. When high-energy photons interact with electrons of a target material, they transfer part of their kinetic energies to the orbital electrons and the photons change directions or frequencies. If the electrons attain sufficient energies beyond their binding energies, they are ejected from the atom, leaving the atoms ionised. MAC values of samples S4 and S5 slightly increased towards the maximum energy of 15,000 keV. This occurs in the high-energy range where pair production is dominant.

The linear attenuation coefficient

The energy-dependent variations of the LAC values are presented in Figure 2. Since the LAC values are obtained by multiplying the MAC values by density, the denser the material, the greater its LAC or the capacity to absorb radiation per unit of its length. Also, the higher the energy (wavelength) of the radiation, the greater its capacity to pass through a material. As seen in Figure 2, the variations of LAC values are similar to the changes in MAC values with changes in photon energy. It is also clearly seen in Figure 2 that all the samples have a continuous decrease in the LAC values with increasing photon energy. LAC values decreased in the order S4 > S5 > S1 > S3 > S2. It can also be seen that at 50 and 80 keV, S5 and S4 samples respectively indicated sharp jumps in their LAC values. S1 and S3 samples had their LAC values coincide from 0 to 60 keV. S1 and S2 samples had their LAC values coincide at photon energies between 120 and 1800 keV. S4 and S5 samples had higher LAC values, while S1 and S3 samples had average LAC values and the S2 sample had the least.

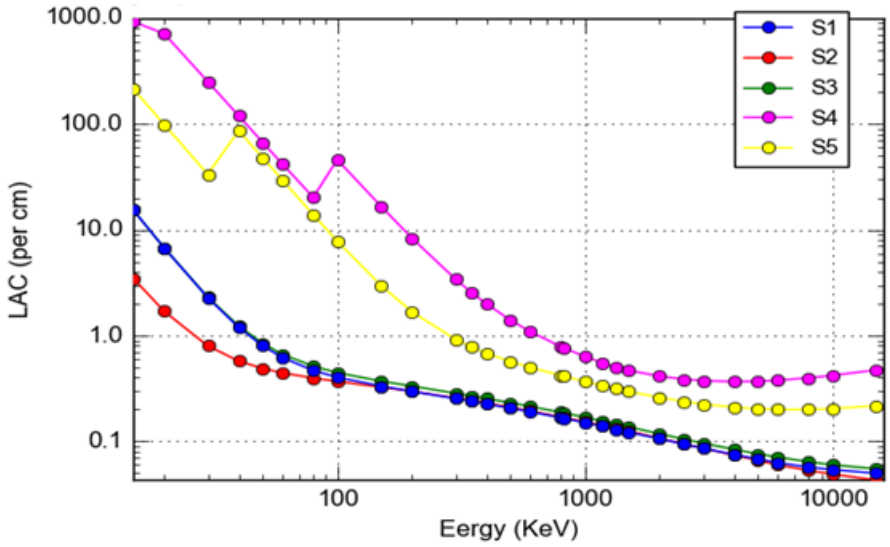

Figure 2: Variation of LAC values with energy

Half-value layer

The HVL is a common parameter used in radiation-shielding studies. Since HVL is inversely proportional to LAC, the higher the LAC value for a material, the lower its HVL and the better its radiation-shielding property. Figure 3 shows the variations in HVL values plotted against the photon energy. As seen from Figure 3, for all the samples investigated, the values of HVL increased with increasing photon energy in the order S4 < S5 < S3 < S1 < S2. This increase is due to the reduced photon interaction cross-section with atoms at high energies. Thus, the glass is more space-efficient at lower energies but is less space-efficient at higher energies.

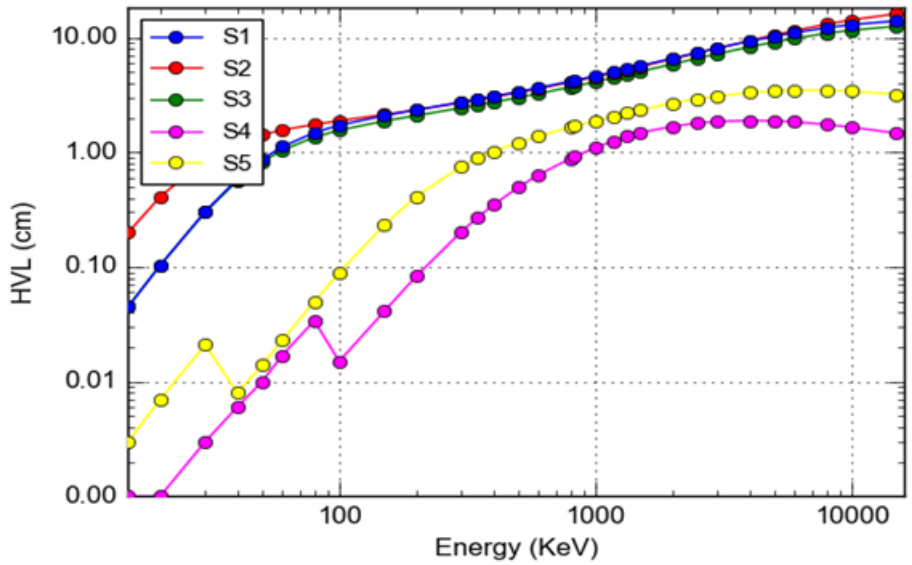

Figure 3: Variations of HVL values with energy

Mean-free path

Another important parameter investigated in this study is the MFP of photons in the different glass types. Similarly, MFP is inversely proportional to LAC. This implies that the higher the LAC values of a material, the lower its MFP and the better its radiation-shielding property. The physical meaning is that a material with higher LAC does not permit radiation to travel that deeply into the material. This is a crucial parameter to consider in radiation-shielding and design. The variations in MFP as a function of the incident photon energy for all the glass samples investigated in this study are presented in Figure 4. Figure 4 shows that MFP values increased with increasing photon energy. In the low-energy zone, these values are close to zero. However, in the region where Compton scattering dominates, photons tend to scatter and are less likely to be absorbed within the shielding material. Thus, thicker materials are needed since photons have longer mean-free paths (Waly *et al.*, 2018b). The scattered photons could travel in unpredictable/unexpected directions – for example, coming into contact with people. This is a problem that any shielding material must try to address to minimise human exposure to scattered photons. The sudden increase in HVL and MFP values in the middle energy region is attributed to the Compton scattering. By observing the variations in MAC, LAC, HVL and MFP values, it can be seen that the S4 sample has the best shielding characteristics among the examined samples.

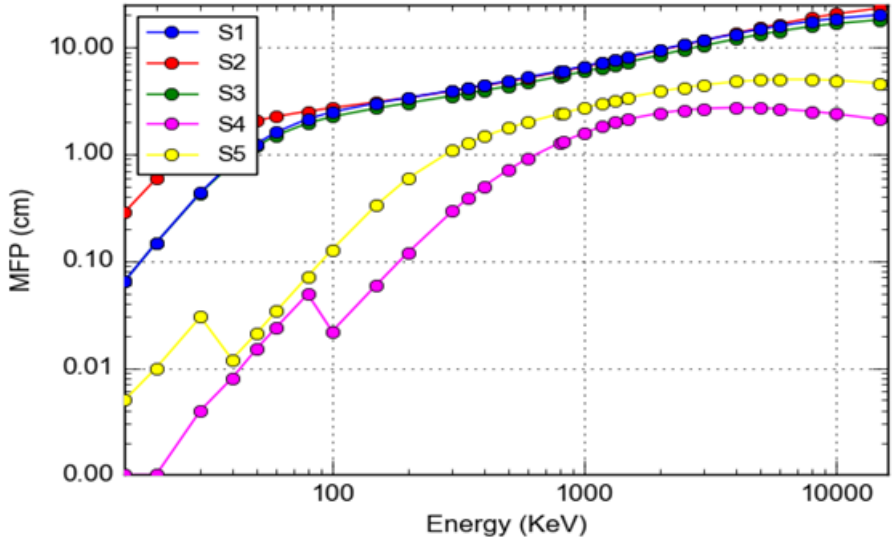

Figure 4: Variations of MFP values with incident photon energy

The effective atomic number

A single number for all energies cannot represent the atomic numbers of chemical compounds or mixtures as in the elements. So the effective atomic number, Z_{eff}, is used for composite samples. The variations in the effective atomic numbers with changes in incident photon energy are presented in Figure 5. The observed variations are in the order of S4 > S5 > S1 > S2. These variations are attributed to the photoelectric effect and coherent and incoherent scattering photon interaction mechanisms. Figure 5 shows that samples S1, S3 and S2 have low effective atomic numbers in the low-energy region, which remains almost constant in the high-energy region – except for S1 and S3, which slightly increase. It can also be seen that samples S4 and S5 have high values in the low-energy region which gradually decrease and rise again in the high-energy region. At the low-energy region, where the photoelectric effect is dominant, the incident photon interacts with the electrons in the material, and the photon loses its kinetic energy to either excite the electrons or dislodge them from their positions, causing ionisation of the atoms. As the photon energy increases, Compton scattering becomes predominant. In this case, the photon interacts with the electrons but the photon does

not get stopped completely. Instead, they change directions and get scattered in the material while continuing to interact with the electrons, leaving behind trails of excited and dislodged electrons in the material. At higher photon energy, pair production becomes more predominant than in all the previous processes. In general conditions, effective atomic number values should be high in low-energy regions. This implies that S4 and S5 samples with high effective atomic number values in the low-energy region have better photon shielding properties than S1, S2 and S3 samples.

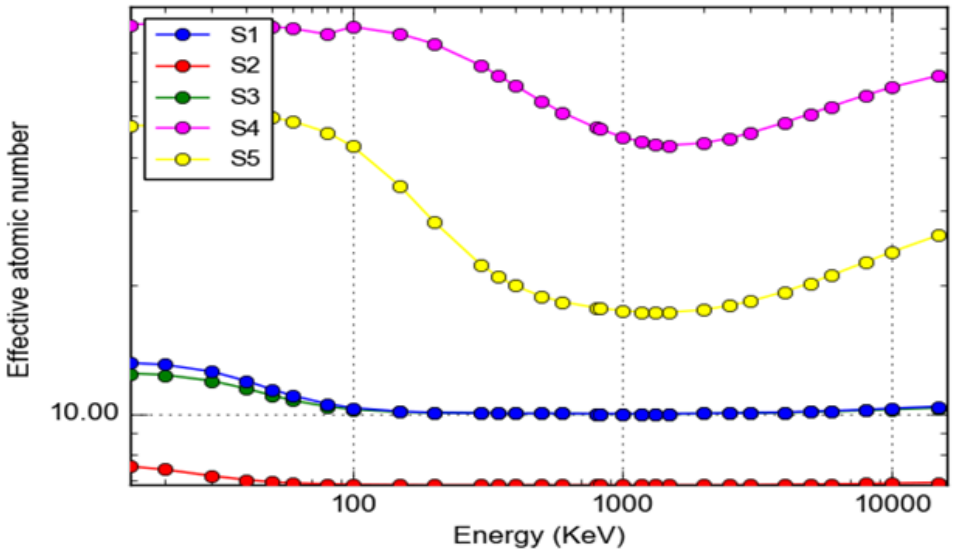

Figure 5: Variations of effective atomic number against energy

Conclusion

A study of the radiation-shielding properties of tellurite, bismuthate, silicate, borate, and phosphate glass was conducted using the Phy-X/PSD simulation software. The results showed that bismuthate glass (S4) had the highest MAC and LAC values followed by tellurite (S5), silicate (S3), phosphate (S1) and borate (S2) glass respectively. The results also showed that bismuthate glass had the lowest HVL and MFP values followed by tellurite, silicate, phosphate and borate glass respectively. Since materials with high MAC and LAC values, and low HVL and MFP values are better photon attenuators, this study found bismuthate glass to be better radiation-shielding material than the rest of the glass examined in this study. It is been observed that bismuthate glass has a higher density compared to other studied glass, which implies that density affects the shielding properties of a material. On the other hand, borate glass presented the least shielding potential compared to phosphate, silicate and tellurite glass. Borate glass was observed to have the least or lowest properties in shielding, making them the material with the worst shielding properties. It was observed that the weighting mole fractions of a compound affects its effective atomic number and its variations with photon energy; this was discovered when individual elements were studied with incident photon energy.

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Glossary

Compton scattering: the process by which high-energy photons are scattered following their interactions with the electrons of a material

Gamma ray: a penetrating form of electromagnetic radiation that emanates from the radioactive decay of atomic nuclei.

Ionising radiation: radiation that carries sufficient energy to knock off electrons from the atoms or molecules of a material

keV: written in full as kilo electron volt, is the kinetic energy gained by a single electron accelerating through an electric potential difference of one volt in a vacuum.

Pair production: the process by which a high-energy photon creates an electron and a positron pair when it passes close to the nucleus of an atom

Photoelectric effect: the emission of electrons from a material following absorption of electromagnetic radiation such as gamma rays, X-rays and ultraviolet light.

Photon attenuator: a material with a high potential to stop photon radiation such as gamma rays and X-rays

Photon radiation: is a class of massless and chargeless particles or waves that form the electromagnetic spectrum.

Photon shielding: is the use of appropriate materials that can reduce the number of incoming photons and their energy to protect humans and the environment from their detrimental effects

Radiation attenuation: the process by which a material slows down or reduces the energy of an incoming radiation

Radiation dosimetry: is the measurement, calculation and assessment of the ionising radiation dose absorbed by an object, usually the human body.

Radiation syndrome: is a collection of health effects caused by exposure to high amounts of ionising radiation.

Radiation: is the emission or transmission of energy in the form of waves or particles through space or a material medium.

Radiology: is a branch of medicine that uses medical imaging to diagnose diseases and guide their treatment.

Radiotherapy: is the treatment of cancer using ionising radiation.

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The Influence of Harness Design on Forelimb Biomechanics in Pet Dogs

Lauren Dowdeswell and Lucianna Churchill, University Centre Reaseheath

Abstract

Dog harnesses are a popular walking aid for pet dogs. Research has focused on the biomechanical impact of assistance dog harnesses; however, this is lacking in the pet dog harness industry. This study aimed to explore the impact of six different harness types on canine biomechanics compared to a standard (base) collar, speci. cally analysing shoulder extension, shoulder flexion, elbow extension and elbow flexion. A high-speed recording device recorded a total of 21 videos per dog (n=30), and analysis demonstrated that the straight-front harness allowed for the most elbow and shoulder extension and flexion, whereas the front clip allowed for the least elbow and shoulder flexion and extension. By directly comparing the six harnesses, three of which are new to research inclusion, the evidence drawn demonstrates which harnesses should be utilised more and which should potentially be avoided. These results provide a foundation for future research, and recommendations have been outlined, specifically considering breed difference, morphological impacts and long-term effects of harness design on canine gait. With advancements in the canine industry, this research is crucial for maximising safety and potentially preventing or delaying various musculoskeletal disorders.

Keywords: Biomechanical impact of pet dog harnesses, Elbow and Shoulder flexion and extension, Canine gait during harness use, Canine pet harnesses, Quintic Software for canine gait analysis, Restrictive vs. non-restrictive harnesses

Introduction

The use of harnesses for pet, working and sport dogs is becoming increasingly popular in the United Kingdom (Cobb *et al.*, 2015; Grainger *et al.*, 2016; Shih *et al.*, 2021). Research has explored the use of harnesses on guide dogs (Peham *et al.*, 2013), and the behavioural impacts of harnesses (Grainger *et al.*, 2016; Kumpulainen *et al.*, 2021); however, there is a noticeable lack of research focusing on harnesses for pet dogs. Harness brands Ruffwear (2020) and Julius K9 (2020b) have conducted research to demonstrate the benefits of their own harnesses, however there are no comparisons between brands. There is a risk that research conducted by parties with financial investment may withhold data to maintain a positive public image (Fabbri *et al.*, 2018), which therefore lowers the reliability of their findings.

Canine biomechanics

Nagymáté *et al.* (2018) conducted gait analysis using three Julius K9 harnesses and found no significant differences between the three harnesses when compared to unleashed movements. This directly challenges Julius K9's reputation for causing shoulder injuries and limiting movement (Thompson, 2020). Julius K9 (2020a) states that this opinion is caused by a lack of research and misinformation spread on social media.

Pálya *et al.* (2022) completed a follow-up study investigating two 'restrictive' harnesses and two 'non-restrictive' harnesses, including three Julius K9-branded harnesses. They could not recommend one

particular harness, as the results gathered depended on the breed and use of the harness (Edmunds *et al.*, 2021). This further shows that harness impact depends mainly on the build of the individual dog, suggesting that opinions on certain brands should not be generalised.

Zink (2019) hypothesised that a straight-front harness would restrict movement more than a y-front harness, but found the opposite. They assessed gait at walking speed and trot speed, and found that the y-front allowed for less shoulder extension than the straight front. They assumed this to be caused by incorrect harness fitting and is therefore a limitation of the study as other research has shown that ill-fitting harnesses can impact gait (McMillan and Spaulding, 2022).

Lafuente *et al.* (2018) completed a similar study utilising a treadmill but implemented markers on the dogs for angle analysis. They also found y-shaped harnesses reduced shoulder extension more than the straight front. While markers can increase accuracy (Moro *et al.*, 2022), studies have shown that markers can influence the dogs' natural motion due to the treadmill pressure increasing skin movement (Schwencke *et al.*, 2012). This means that markers may lead to inaccurate results due to the causation of extraneous variables.

Söhnel *et al.* (2022) advocate for treadmill-based gait analysis due to its speed consistence and reduced movement variability compared to overground locomotion. However, Piccione *et al.* (2012) expressed that minimal treadmill experience may impact a dogs' behaviour, therefore influencing their gait. Treadmills only allow for the joints to perform certain movements (Torres *et al.*, 2013), which could potentially alter their gait (McIntyre, 2019). This may misrepresent the impact of harnesses on typical pet usage.

Musculoskeletal disorders

O'Neill *et al.* (2017) identified that musculoskeletal disorders, such as osteoarthritis, are a leading cause of death in German Shepherd Dogs. Mocchi *et al.* (2020) found extensive reports of osteoarthritis in veterinary practices. Osteoarthritis is the irreversible, progressive degeneration of bone and cartilage (Zeira *et al.*, 2018). Belshaw *et al.* (2020) looked into gait changes caused by osteoarthritis, finding that exercise was severely impacted. Considering the influence of a harness on the musculoskeletal system, it is likely that dogs will adapt their gait to accommodate a harness during exercise, and this adaptation may be more severe if the harness is ill-fitting (Anderson, 2020).

Harnesses can alter posture, causing asymmetries between specific joints (Packer and Tivers, 2015). This can significantly impact breeds with conformational disorders, such as English Bulldogs (Escobar *et al.*, 2017). Conformational disorders occur in breeds with exaggerated body structures, causing negative impacts to their health and welfare (Packer *et al.*, 2023). These body structures have been shown to influence the movement of different limbs and joints due to the predisposition of orthopaedic diseases and the interference with locomotion, causing changes in asymmetry and peak vertical force (Escobar *et al.*, 2017; Humphries *et al.*, 2020a; Humphries *et al.*, 2020b; Jeandel and Garosi, 2018).

Injury can lead to gait abnormalities due to compensating to reduce weight-bearing on the affected limb(s) (Carapeba *et al.*, 2016; Goldner *et al.*, 2018). Żuk and Księżopolska-Orłowska (2015) investigated arthritis in children, finding a reduced range of motion in the affected limb, and microtrauma in the unaffected limb. Although this research investigated children, Meeson *et al.* (2019) recently discovered that both dogs and humans share commonalities in osteoarthritis, such as areas of development, and causes of development. Due to this, it is likely that dogs would show similar gait abnormalities caused by the compensation.

Additionally, equine research has established that lameness causes compensatory weight redistribution onto the non-affected limbs, resulting in gait abnormalities due to the transfer of vertical force (Bragança *et al.*, 2020; Clayton, 2016; Maliye and Marshall, 2016). Given the musculoskeletal similarities between horses and dogs, similar compensatory redistribution is expected in dogs (Ahmed *et al.*, 2019).

Alternatives to harnesses

Many trainers and behaviourists recommend the use of collars over harnesses due to the misconception that harnesses actively cause a dog to pull (Landsberg *et al.*, 2023). This is incorrect; harnesses were designed to enable sled dogs to pull (Ramey *et al.*, 2022), but they do not inherently cause pulling (Shih *et al.*, 2020).

Townsend *et al.* (2020) stated that collars can cause tracheal and oesophageal issues, especially in brachycephalic breeds. Harnesses can prevent this by redistributing pressure across the body (Carter *et al.*, 2020; Hunter *et al.*, 2019). However, Shih *et al.* (2021) found this enabled significantly more pulling, so headcollars may be more suitable for these dogs (Grainger *et al.*, 2016). The AKC (2021) express that harnesses help to avoid injury and discourage pulling but have a greater escape risk. Both Takáčová *et al.* (2021) and Ward (2021) state that this is usually due to user fitting error, rather than harness design, so still recommends their use.

Gaps in the research

Despite the vast array of harness designs available, comparative biomechanical research is severely limited. Blake *et al.* (2019) emphasised the need for direct comparisons between multiple harness designs, specifically in relation to gait. Improved understanding of the biomechanical impacts of harnesses may aid in harness production, ensuring brands offer safe and secure harnesses. Furthermore, statistical information on a wider variety of harnesses is needed so owners can make informed decisions by providing results on the impact each style/design can have on biomechanics.

This study will close this gap by investigating the influence of harness design on shoulder and elbow biomechanics, specifically flexion and extension, in pet dogs. This new approach may facilitate the further study of the long-term effects of harnesses. This research will provide the vital information needed for owners to choose harnesses and to bring awareness to the variety of styles available.

Canines have various morphologies depending on their breed (Bannasch *et al.*, 2021). Improving owner awareness of the variety of harnesses available means they are more adept to finding a well-fitting, suitable harness. This can therefore prevent the risk of harnesses having a negative impact on the dogs' biomechanics (Preston *et al.*, 2012).

Methodology

Data collection occurred at the University Centre Reaseheath (UCR), utilising various indoor classrooms to avoid weather-related disruptions (Edwards *et al.*, 2018). Advertisement of the study was released on social media in an attempt to achieve the desired sample size (n=30). This surpasses similar research, and provided sufficient data within the time constraints (Morse, 2015). Ethical approval was obtained on 25 June 2022, before data collection began, from the UCR Ethics Committee, in accordance with the Animal Welfare Act 2006 (ethics approval reference 221405LDsub4).

The study was open to all dogs, excluding the four banned breeds in the UK (Pitbull Terrier, Japanese Tosa, Dogo Argentino and Fila Brasileiro; The Dangerous Dogs Act, 1991). Due to accepting all breeds, one harness of each size, per harness type, was required. Dogs had to be over the age of 18 months to prevent the open growth plates of puppies causing abnormal results (Virag *et al.*, 2022). They also had to be fit and well, with no existing musculoskeletal disorders, due to these impacting biomechanics (Adrian *et al.*, 2019) or causing harm/discomfort (Shih *et al.*, 2021).

Participants were recruited through social media advertisement explaining the study and inviting participation. Staff who enrolled their dogs in the university kennels were also approached regarding the inclusion of their dogs. These were included due to the convenient access to the dogs during the working day.

Potential participants were required to complete a pre-trial questionnaire per dog before their trial could begin. Three screening questions were included to ensure three main requirements. The first being that the owner was at least 18 years old (UK General Data Protection Regulation, 2021). Secondly, that the dog was over 18 months old. Finally, ensuring the dog had no known musculoskeletal disorders.

The remainder of the questionnaire gathered information pertaining to each participant, such as breed and age. All owners were asked if their dog was likely to become distressed during harness fitting. If yes, the participant was excluded to ensure researcher safety (Thompkins *et al.*, 2016).

Video data were collected using a high-speed 60fps (frames per second) camera (iPhone 11), for simplicity and availability. Each dog was fitted with a collar as a control measure (Simmons *et al.*, 2015), and each harness was fitted by, or under the guidance of, the author. This was to ensure they were correctly fitted and sized to avoid either factor becoming an extraneous variable and influencing results (Bremhorst *et al.*, 2018).

Each dog was walked down a 4m (metre) walkway on a 1.3m lead, marked using a 5m lead, with a camera situated 1–2m away on a stand. This distance was altered depending on the height of the dog. Three repetitions per harness/collar were recorded; any unsuccessful videos were re-recorded. Each video was then transferred onto the study laptop via Telegram and saved in a password-protected Microsoft Vault.

While all participants were trialled in the same harnesses, the order of these was randomised. This may have negated the impacts of habituation to harness wear or trial behaviour expectations (Suresh, 2011). This is especially relevant for dogs who do not normally wear harnesses. Future research should consider the benefits of randomised studies and/or training prior to the trial.

The independent (explanatory) variable was the harness style (see Appendix 1), and the dependent (response) variable were elbow extension, elbow flexion, shoulder extension and shoulder flexion (see Appendices 2 and 3). This study included a third variable, a (random) data variable, which was the dogs involved. As a control measure, each dog was walked on the base collar to establish an approximate base-gait measurement. Owners picked the direction of walking, and this remained constant for each video to ensure directional changes had no impact.

Videos were then analysed using Quintic Biomechanics Software (Quintic Software, 2009), due to its ability to provide high-speed video capture and its allowance for biomechanical analysis. For each video, the gait cycle was broken into three phases: (1) full elbow extension/shoulder flexion (as we can measure the different angles on the same frame), (2) elbow flexion and (3) shoulder extension (see Appendices 2 and 3). These were then measured using Quintic Manual Angular Software.

Each angle was then exported onto a large Excel document for each walk. The mean and R Studio were used to fully analyse the data. Primary data was collected; although this can be more expensive and time-consuming to complete, data gathered first-hand has increased reliability and validity (Vetter, 2017).

A Generalised Linear Mixed Model (GLMM) was used for data analysis, due to being appropriate for large amounts of clustered data (Rabe-Hesketh and Skrondal, 2010); this study collected approximately 2500 individual pieces of data. As previously noted, three different walks were recorded per dog per harness per angle. From there, each individual piece of data was put onto a final data set, before being uploaded onto R Studio for GLMM analysis. Outliers have not been removed, as GLMMs are flexible and can handle random effect and non-normal distributions, so this step was not necessary (Bolker *et al.,* 2009). Alongside this, the median and interquartile range were found for each harness type and angle (as shown in Table 1).

Due to the third, random variable – the dogs themselves – the GLMM accounted for this by basing itself on the entire sample population instead of each individual subject, which allowed for sparse sampling (Huang and Li, 2007). This is why the raw data set was used, as GLMM works best with large sets of data instead of means, and it can appropriately incorporate/exclude any outliers.

A normality test is not required for a GLMM due to the large amount of data it handles and the assumption that there will be non-normal results within the data collected (Stroup, 2015). However, an omnibus normality test (Shapiro-Wilk) was still performed to assess the normality of the whole data set ($p=0.05$) and to justify the correct descriptive statistics to report. The data was not normally distributed ($p<0.05$), so the median and interquartile range were used to remain consistent across the data.

Alongside this, 28 individual Shapiro-Wilkes normality tests were performed for each harness/collar and angle combination (elbow extension/straight front, elbow extension/chest plate, for example – see Appendix 4) as supplementary information. Although some of these normality tests were normal, if there is any non-normal data then the assumption that the entire dataset is non-normal is made (Field, 2017).

However, these normality tests were used to decide which pairwise tests to use for the result comparisons. A one-way ANOVA was used for shoulder flexion as all results were normal, and a Kruskal Wallis was used for the other three angles, as the results were a mixture of normal and non-normal.

Health and safety, and ethics

The health and safety, and ethics for this study were upheld, meaning this research was ethically produced, and demonstrates to future researchers how to ethically conduct dog-related studies (Woodin, 2015). Particularly, one dog was excluded from the trial due to their negative reaction to the study location, so removing him from the study was the most ethical decision (Tasker *et al.*, 2018).

Alongside this, participants never came into contact with other dogs outside of their household (King and Zohny, 2022). Timeslots were given to each participant, allowing sufficient time for them to leave before the next participant's trial. This ensured that dogs did not come into contact with each other; to give us time to finish each harness; and to ensure the dog had time to acclimatise to the room before beginning the trial.

Any dogs with nervousness or disfavour of having their paws touched were handled by the owner to protect researchers from any reactions (Health and Safety at Work Act 1974), but to also keep anxiety levels of the dogs as low as possible (Animal Welfare Act 2006). Although changing the walker for some dogs may be an

extraneous variable, the author prioritised the ethics and safety of each participant as paramount (National Dog Warden Association, 2012).

Results

A GLMM was performed to compare the influence of each harness on elbow and shoulder extension and flexion. Descriptive statistics are presented in Table 1, with results expressed as medium and interquartile range.

Results are recorded as (median (IQR: 25th percentile – 75th percentile)).

Joint	Angle	Base Collar		Chest Plate		Front Clip		No-Pull		Step-In		Straight Front		Y-Front	
		Med	*IQR*	*Med*	*IQR*	*Med*	*IQR*	*Med*	*IQR*	*Med*	*IQR*	*Med*	*IQR*	*Med*	*IQR*
Shoulder	Extension	97.4°	88.5° - 102.5°	88.5°	80.9° - 97.6°	84.7°	79.6° - 95.2°	88.2°	76.8° - 95.2°	86.3°	80.9° - 96.2°	93.8°	86.0° - 99.6°	93.5°	84.3° - 99.3°
	Flexion	91.3°	85.9° - 97.6°	88.4°	82.5° - 94.5°	84.1°	78.2° - 90.7°	85.7°	79.7° - 91.2°	87.6°	82.8° - 93.8°	89.6°	85.4° - 94.9°	88.9°	84.4° - 93.8°
Elbow	Extension	137.0°	131.8° - 141.4°	134.2°	130.5° - 138.3°	132.1°	127.1° - 135.2°	133.2°	128.3° - 136.7°	133.9°	129.4° - 139.3°	134.6°	130.1° - 140.4°	135.9°	130.8° - 139.7°
	Flexion	80.9°	73.7° - 86.9°	81.4°	74.0° - 84.2 °	76.4°	69.6° - 81.0°	78.0°	74.0° - 83.1°	75.7°	71.0° - 80.5°	79.7°	75.9° - 84.3°	79.5°	75.2° - 85.0°

Table 1: Median and interquartile range of each harness design and base collar

The influence of each harness design on shoulder and elbow extension and flexion, compared to the base collar is displayed. The descriptive statistics are recorded as (median (IQR 25th percentile – 75th percentile)).

As indicated below in Figure 1, the front clip (132.1° (IQR: 127.1° – 135.2°)) and no-pull (133.2° (IQR: 128.3° – 136.7°)) had the most significant impact on elbow extension compared to the base collar (137.0° (IQR: 131.8° – 141.4°)). The chest plate (134.2° (IQR: 130.5° – 138.3°)) and step-in (133.9° (IQR: 129.4° – 139.3°)) both had a significant impact, but less so than the aforementioned harnesses. However, neither the straight front (134.6° (IQR: 130.1° – 140.4°)) or y-front (135.9° (IQR: 130.8° – 139.7°)) had a significant impact on elbow extension.

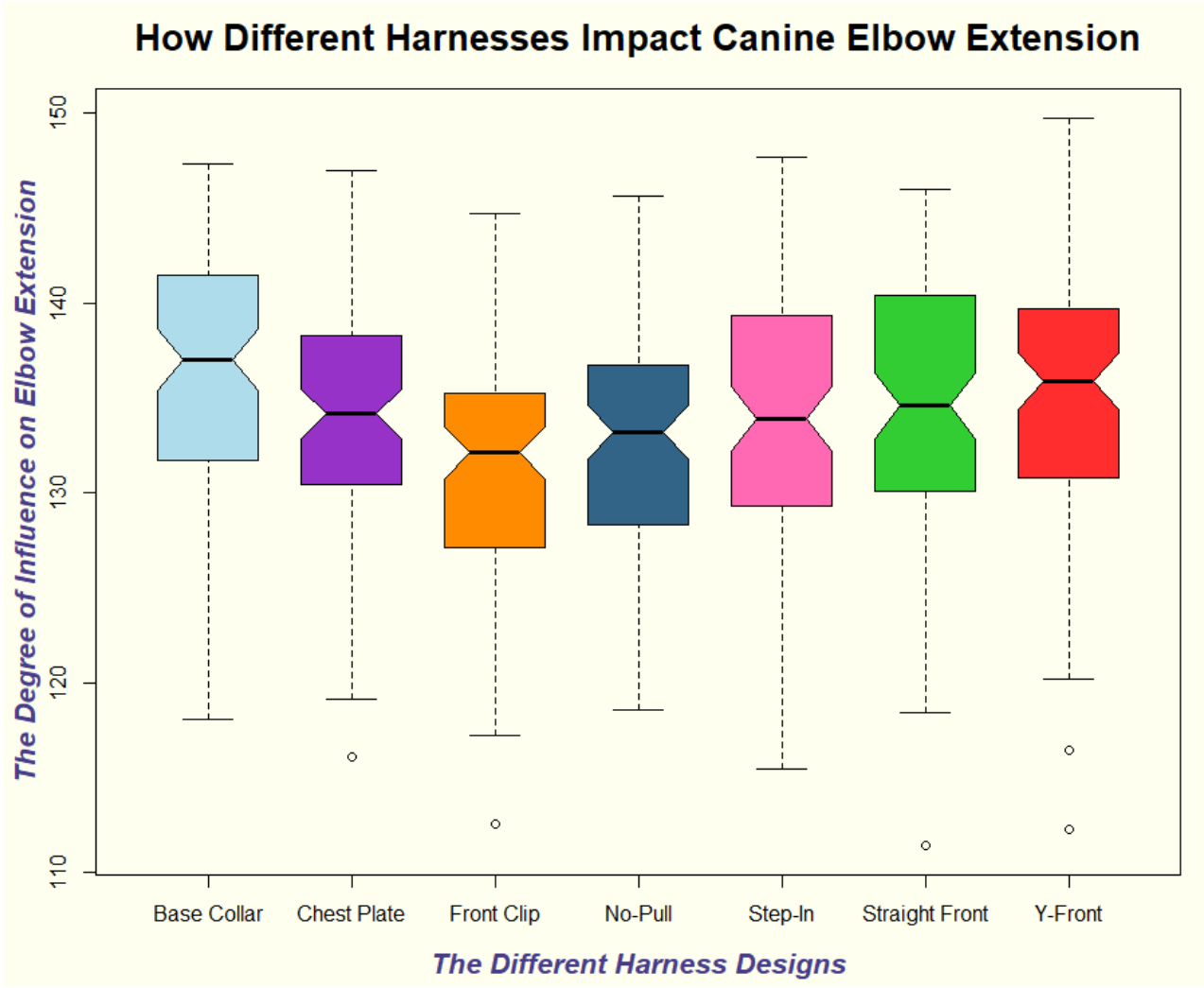

Figure 1: Box-and-whisker plot showing elbow extension for each harness design

The degree of canine elbow extension for each harness design and base collar is displayed (n=60). This is displayed as a box-and-whisker plot with outliers.

(GLMM: chest plate t = -0.942, p=0.034; front clip t = -2.123, p<0.001; no-pull t = -5.642, p<0.001; step-in t = -4.057, p=0.027; straight front t = -2.210, p=0.078; y-front t = -1.765, p=0.346).

Conveyed in Figure 2, the front clip (76.4° (IQR: 69.6° – 81.0°)) and step-in (75.7° (IQR: 71.0° – 80.5°)) had the most significant impact on elbow flexion compared to the base collar (80.9° (IQR: 73.7° – 86.9°)). The no-pull (78.0° (IQR: 74.0° – 83.1°)) also had a significant impact, but not to a considerable degree. The straight front (79.7° (IQR: 75.9° – 84.3°)), y-front (79.5° (IQR: 75.2° – 85.0°)) and chest plate (81.4° (IQR: 74.0° –_84.2 °)) did not have a significant impact on elbow flexion. (See Appendix 5 for the pairwise comparisons).

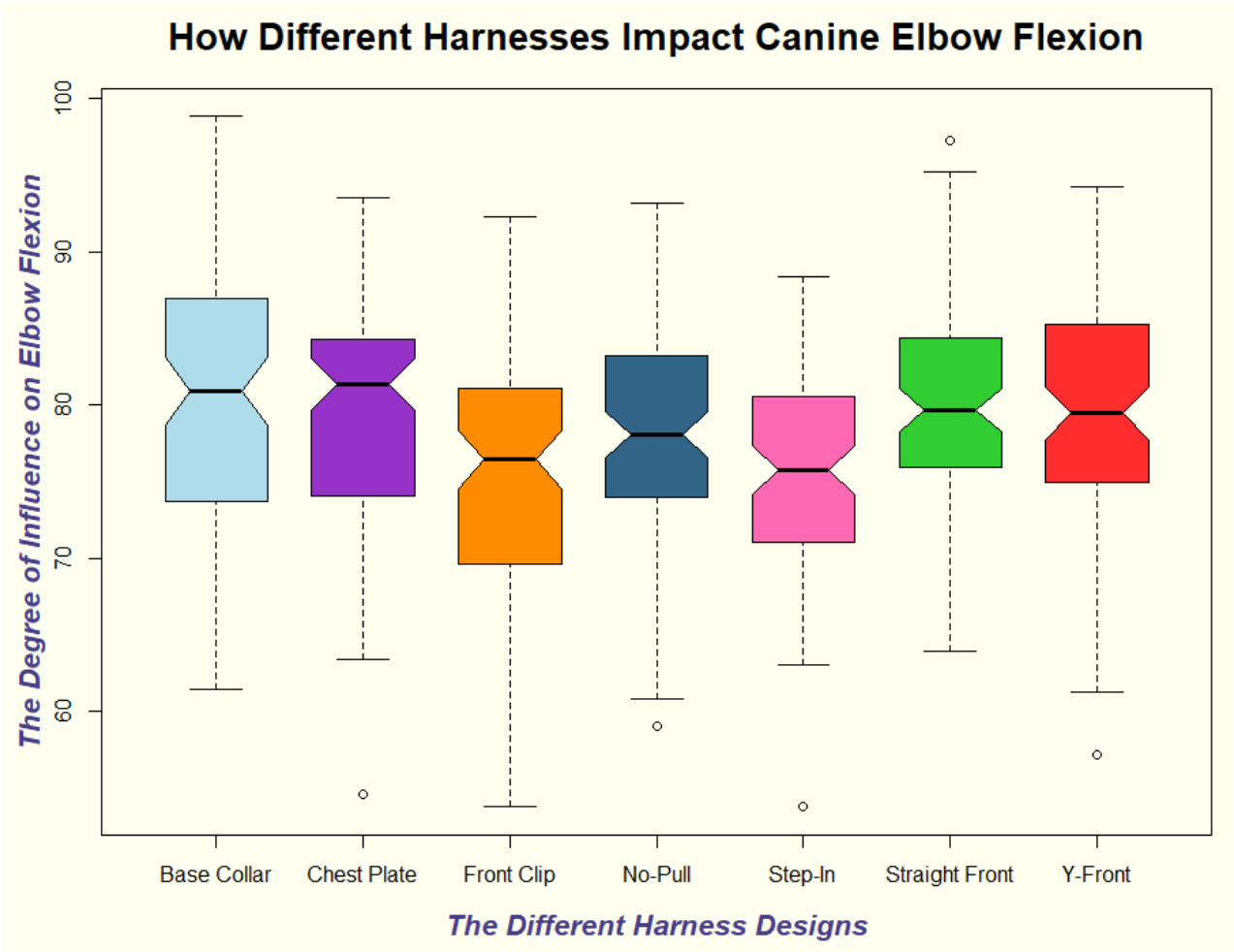

Figure 2: Box-and-whisker plot showing elbow flexion for each harness design

The degree of canine elbow flexion for each harness design and base collar is displayed (n=60). This is displayed as a box-and-whisker plot with outliers.

(GLMM: chest plate t = -0.755, p=0.511; front clip t = -0.658, p<0.001; no-pull t = -5.769, p=0.003; step-in t = -3.006, p<0.001; straight front t = -5.471, p=0.501; y-front t = -0.673, p=0.451).

Exhibited in Figure 3, the chest plate (88.5° (IQR: 80.9° – 97.6°)), front clip (84.7° (IQR: 79.6° – 95.2°)), no-pull (88.2° (IQR: 76.8° – 95.2°)), step-in (86.3° (IQR: 80.9° – 96.2°)), straight front (93.8° (IQR: 86.0° – 99.6°)) and y-front (93.5° (IQR: 84.3° - 99.3°)) all had a significant impact on shoulder extension compared to the base collar (97.4° (IQR: 88.5° – 102.5°)). (See Appendix 6 for the pairwise comparisons).

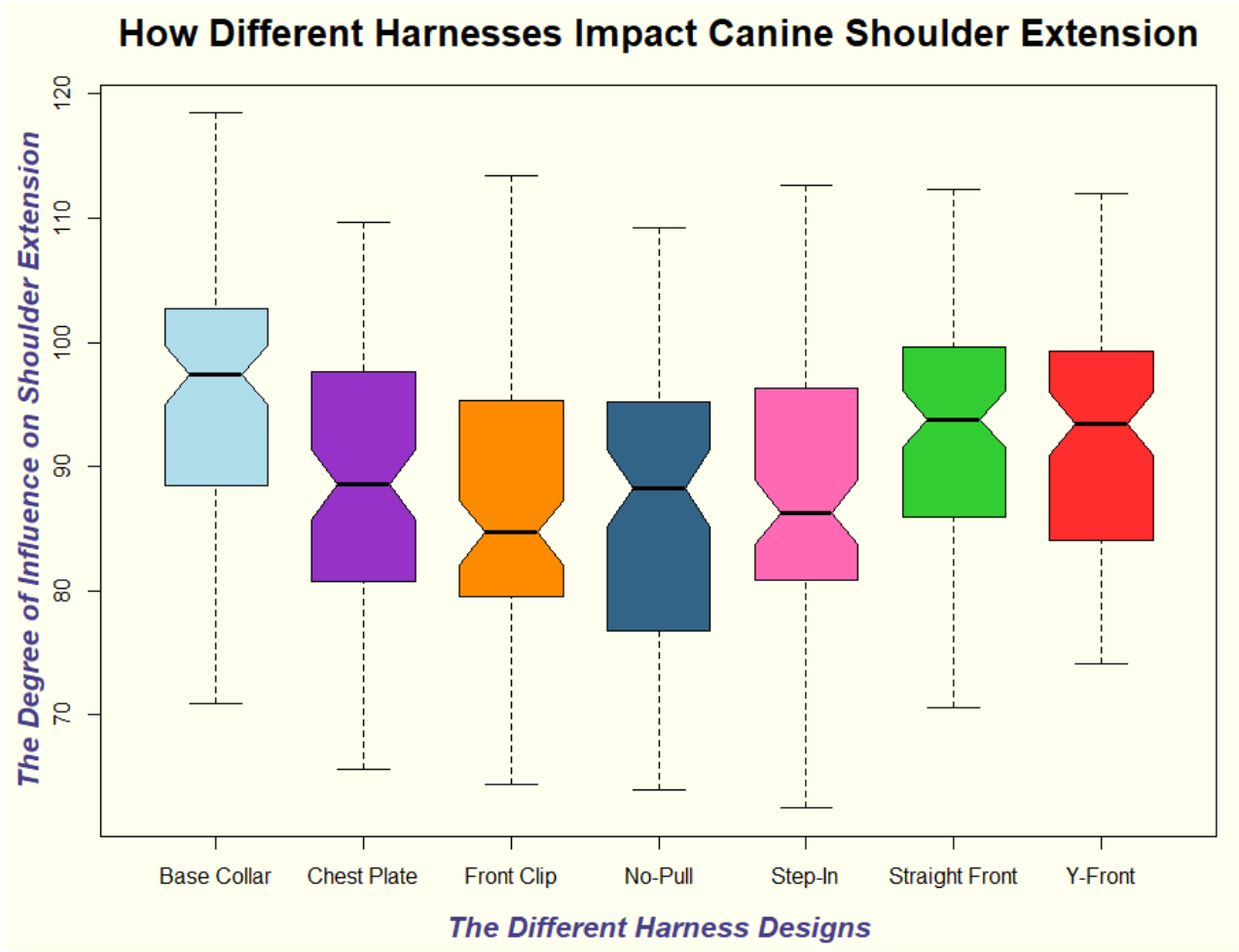

Figure 3: Box-and-whisker plot showing shoulder extension for each harness design

The degree of canine shoulder extension for each harness design and base collar is displayed (n=60). This is displayed as a box-and-whisker plot with outliers.

(GLMM: chest plate t = -3.863, p<0.001; front clip t = -7.403, p<0.001; no-pull t = -9.514, p<0.001; step-in t = -10.030, p<0.001; straight front t = -8.340, p<0.001; y-front t = -3.547, p<0.001).

Displayed in Figure 4, the chest plate (88.4° (IQR: 82.5° – 94.5°)), front clip (84.1° (IQR: 78.2° – 90.7°)), no-pull (85.7° (IQR: 79.7° – 91.2°)), step-in (87.6° (IQR: 82.8° – 93.8°)) and y-front (88.9° (IQR: 84.4° – 93.8°)) all had a significant impact compared to the base collar (91.3° (IQR: 85.9° – 97.6°)). The only harness to not significantly impact shoulder flexion was the straight front (89.6° (IQR: 85.4° – 94.9°)). (See Appendix 7 for the pairwise comparisons).

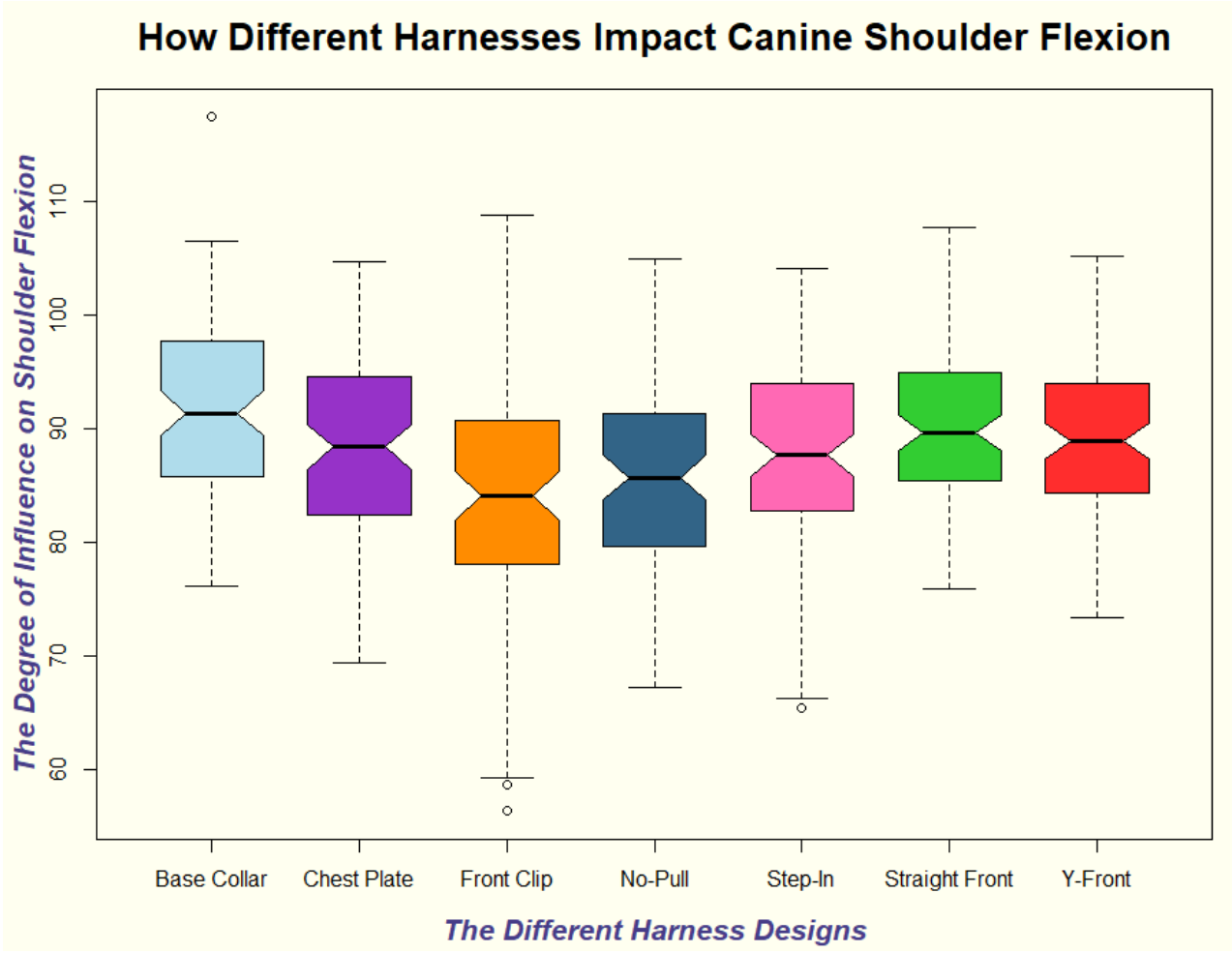

Figure 4: Box-and-whisker plot showing shoulder flexion for each harness design

The degree of canine shoulder flexion for each harness design and base collar is displayed (n=60). This is displayed as a box-and-whisker plot with outliers.

(GLMM: chest plate t = -3.557, p<0.001; front clip t = -4.736, p<0.001; no-pull t = -9.184, p<0.001; step-in t = -7.824, p<0.001; straight front t = -5.079, p=0.02; y-front t = -2.330, p<0.001).

Across all four analyses, the front clip is the only harness that significantly reduced all four angles measured. Opposingly, the straight-front harness did not significantly reduce three of the angles measured. The only significant reduction was of shoulder extension; however, every harness significantly reduced this angle compared to the collar. The y-front did not significantly reduce elbow extension or flexion but did significantly reduce shoulder extension and flexion. (See Appendix 8 for the ANOVA and Tukey honest significant difference post-hoc).

The chest plate did not reduce elbow flexion, but significantly reduced both shoulder extension and flexion. It also reduced elbow extension, but to a lower statistical degree. Finally, the no-pull and step-in both reduced every angle, with both significantly reducing shoulder extension and flexion. Both harnesses reduced elbow flexion, but the reduction was more significant in the step-in. Similarly, both also reduced elbow extension, but the reduction was more significant in the no-pull.

Alongside reporting the median and interquartile range, the mean and standard deviation (mean +/- standard deviation) were noted, as presented in Table 2 below. This table displays the influence of each harness design on shoulder and elbow extension and flexion. The coloured shadings are explained in Figure 5. Furthermore,

a post-hoc test was performed for each angle to show more clearly where the differences lie between each harness/collar, and which are significant.

Joint	Angle	Lorke et al., 2017 Maximum Angles	Base Collar	Chest Plate	Front Clip	No-Pull	Step-In	Straight Front	Y-Front
Shoulder	Extension	138.3° +/- 7.2°	95.7° +/- 9.7°	89.0° +/- 10.7°	87.1° +/- 11.3°	86.6° +/- 11.2°	88.1° +/- 10.1°	92.3° +/- 8.9°	92.1° +/- 10.1°
	Flexion	104.5° +/- 6.1°	91.9° +/- 7.6°	87.9° +/- 8.0°	84.3° +/- 10.3°	85.3° +/- 8.0°	87.6° +/- 8.0°	89.8° +/- 7.0°	88.8° +/- 7.7°
Elbow	Extension	152.0° +/- 10.5°	135.8° +/- 7.2°	134.1° +/- 5.8°	131.2° +/- 6.7°	132.5° +/- 6.0°	134.0° +/- 6.4°	134.4° +/- 7.1°	135.0° +/- 6.7°
	Flexion	83.2° +/- 11.1°	80.4° +/- 8.9°	79.8° +/- 7.4°	75.4° +/- 6.7°	77.7° +/- 7.0°	75.6° +/- 6.1°	79.7° +/- 6.5°	79.7° +/- 6.9°

Table 2: Mean and standard deviation of each harness design and base collar

The influence of each harness design on shoulder and elbow extension and flexion, compared to the base collar is displayed. The descriptive statistics are recorded as (mean +/- standard deviation).

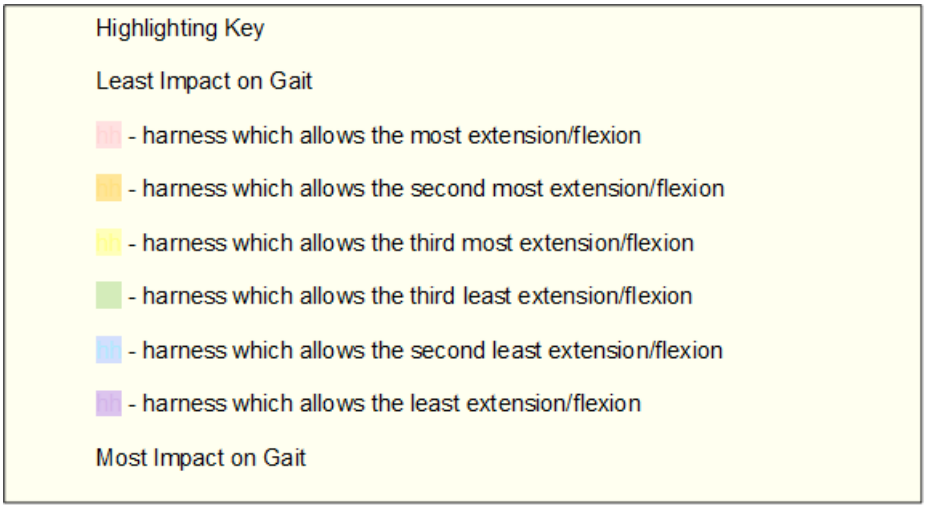

Figure 5: The highlighting key for Table 2

This key displays the harnesses in order of most extension/flexion measured. The base collar is not included.

In Table 2, the base collar was not included in the highlighted order of flexion/extension allowed, as this was expected to be higher due to the absence of contact with the shoulder/elbow. Table 2 also includes the maximum flexion and extension of the shoulder and elbow from Lorke *et al.*'s (2017) study on Beagle dogs for comparison and accuracy assurance.

Discussion

In this study, a comprehensive analysis was performed using several statistical methods, including a GLMM, three Kruskal Wallis with pairwise comparisons and a one-way ANOVA with post-hoc tests. Comparing the results, they differ, which is most likely due to the strengths of these tests and their abilities to work with outliers. Each test was performed to provide valuable insights; however, due to the flexibility and accuracy of

the GLMM when handling large amounts of complex data, the discussion will focus on the results from the GLMM.

Reviewing the results of the GLMM, all six harnesses significantly reduced shoulder extension compared to the base collar. This finding disproves the hypothesis that there would be a significant difference in shoulder extension between the y-front and front-clip harness. However, because every harness impacted this angle, future research could remove the base collar to determine which harness has the least impact, as a collar may not always be an option for an owner (Bailey, 2022; Bolton *et al.*, 2021).

Exploring the front-clip harness, previously considered 'non-restrictive', (Zink, 2019) this harness significantly reduced all four angles measured (EE (132.1°), EF (76.4°), SE (84.7°), SF (84.1°)). The y-front harness also significantly reduced shoulder extension (SE) (93.5°) and flexion (SF) (88.9°) but had minimal impact on elbow extension (EE) (135.9°) and flexion (EF) (79.5°). Blake *et al.*, (2019) deem this impact to be caused by the y-front restricting the scapula angulation (Aspinall and Cappello, 2019), thus reducing movement.

Both the front-clip and y-front harnesses are manufactured with the strap running from the sternum to the dorsal neck, which could potentially influence biomechanics due to the loading on the sternum (Peham *et al.*, 2013). More research would be required to compare strap positioning and sternum impact. This harness design is thought of as being 'non-restrictive' due to the strap not crossing the chest; however, future research would be necessary to definitively prove which strap positioning has the least impact on biomechanics.

When comparing the elbow extension and flexion of the y-front and front clip, it is interesting that only one resulted in significant impact, as this potentially shows that the strap positioning is not the key factor in what influences flexion and extension. Due to the similar style, the other variables of lead position and strap width must be considered. More research is needed to focus on chest-strap width and its interference with elbow movement, as this may be the factor causing the difference in impact. The largest front-clip harness width is 4 inches at the widest part, compared to the largest y-front harness width being 1.5 inches at the widest part. Due to this large difference, it is possible that this factor would have an impact, but more research is needed to prove/disprove this.

The straight front allowed for the largest shoulder extension (93.8°) and flexion (89.6°), and the second-most elbow extension (134.6°), only significantly impacting shoulder extension (79.7°). Many studies have hypothesised that the 'non-restrictive' y-front harness would have less of an impact than the 'restrictive' straight-front harness (Pálya *et al.*, 2022; Sandberg, 2022), yet results have shown the opposite. Zink's (2019) study also found that the non-restrictive y-front significantly restricted shoulder extension when walking. Conclusions can be drawn that the straight front had the least impact on canine biomechanics, which is a key finding for the pet dog community as this may lessen the negative associations with this style (Julius K9, 2020b).

Furthering the comparison between straight-fronts and y-fronts, Pálya *et al.*'s. (2022) study compared the Julius K9 straight front to the new Julius K9 y-front. They found that both harnesses limited gait compared to a standard collar, but there was no significant difference between the two harness designs, thus showing a straight front is not necessarily 'restrictive' compared to a y-front. They concluded that movement restriction depends on the individual dog, and the fit of the harness, however expressed that future research would be needed to support this.

Clayton *et al.* (2017) completed equine research into saddle fitting, and discussed how saddles impact stride, velocity and acceleration. They stated that a poor-fitted saddle impairs the mobility of the horse's back, and inhibits a consistent gait, which can cause lameness and musculoskeletal issues in the long term. Linking this to pet dogs, if an owner struggles to fit a harness, it can impact their gait, which can cause issues over time. Future studies could see the ability of owners to fit different harnesses, and this could encourage brands to increase the harness-fit education they provide.

This research may aid in the safe production and scientifically informed harness advertisement and information to the public. It may also help dispel the incorrect beliefs around harness restriction. As discussed, the y-front harness is commonly sold as 'non-restrictive', but this study has proven that it restricts flexion and extension of both the elbow and shoulder, which is a misrepresentation to the buyers. Alternatively, the Julius K9, which is often labelled as 'restrictive' and is regularly disfavoured by animal professionals and the public, has been proven to have little impact on canine biomechanics. This also supports Julius K9's (2020a) statement regarding the safety and impact of their harness.

Results of this study found that the chest plate and step-in also significantly reduced shoulder extension (chest plate (88.5°), step-in (86.3°)) and flexion (chest plate (88.4°), step-in (87.6°)). However, both also significantly reduced elbow extension (chest plate (134.2°), step-in (133.9°)), but to a lesser degree. The step-in harness did significantly reduce elbow flexion (75.7°), whereas the chest plate did not (81.4°).

Focusing on the step-in harness, this harness has a similar design to the straight front, with the chest strap crossing the chest and shoulders. The Julius K9 straight front has a thicker chest strap that could have impacted gait less, due to the larger distribution of pressure, whereas the step-in chest strap is thinner, so pressure is distributed to a much smaller area. This could explain why the straight front had a much less impact on all measurements compared to the step-in. This refutes the hypothesis that predicted the step-in would have less impact than the straight front, and clearly demonstrates the need for future research to consider chest-strap width and its impact on biomechanics.

Peham *et al.* (2013) measured the pressure distribution of three straight-front guide dog harnesses with different chest-strap widths. They found that when the forelimb extended, the pressure force on the chest increased, but remained low when the forelimb was in flexion. They also found that the pressure force was lowest in the harness with the widest chest strap. Future research could involve similar research but using pet dogs to examine what width chest strap is optimum for low pressure force but still allows for standard flexion and extension.

Moving onto the no-pull harness; this is highly recommended for dogs that pull due to the tightening mechanism under the axilla (armpit), causing slight discomfort to the dog (Company of Animals, 2022). This harness has never been included in research, based on the authors' knowledge. The no-pull reduced all four angles measured: it significantly reduced shoulder extension (88.2°) and flexion (85.7°), and elbow extension (133.2°) and flexion (78.0°), but it reduced elbow extension to a lesser significant degree.

Coincidentally, both the y-front and the no-pull are produced by the brand Halti (VioVet, 2023), which is interesting that their no-pull had such a significant impact on biomechanics, whereas the y-front had very little impact. This demonstrates the requirement for future research to explore the different Halti-branded harnesses and compare how each influences canine gait, potentially supporting their future harness production.

Exploring all six harnesses, the hypothesis that a significant difference in biomechanics would be witnessed depending on the harness worn has been confirmed. However, based on the statistical data, the straight front had the least impact on canine gait, therefore is the authors' top recommendation.

As highlighted previously, there is a need for future research to focus on canine gait and harness impact (Blake *et al.*, 2019). Lafuente *et al.* (2018) discussed the necessity for future research to include multiple harness styles and brands. They also discussed the requirement of studies to include a researcher with experience surrounding dogs and physiology to improve the reliability of the results (Wang *et al.*, 2022). This study has confidently met both future research recommendations by including six harness designs and being controlled by an author with canine experience. Moreover, this study has overcome the limitations of previous studies by ensuring a larger sample size (Zink, 2019), a variety of breeds (Winter, 2013), and controlled extraneous variables, such as the influence of weather or treadmills (Lafuente *et al.*, 2018; Söhnel *et al.*, 2022).

The results of this study have been consistent with the results found by Lorke *et al.* (2017). Their data was included in Table 2 to demonstrate the maximum elbow and shoulder extension, and flexion achieved by healthy Beagle dogs during free movement. As results remained under the threshold identified by Lorke *et al.* (2017), and there is consistency within the ranges, this demonstrates a lack of anomalous data and suggests a high accuracy of the manual angles drawn in this study. Moreover, this suggests high concurrent validity due to the agreement between this study and Lorke *et al.* (2017).

Alongside this, internal consistency reliability has been assured, as results from each harness style have remained consistent (Salonen *et al.*, 2021). Both construct and content validity have also been upheld by ensuring the software used for analysis was specifically for biomechanics (Topál *et al.*, 2019), and that all angles were measured in the same way (Rocznik *et al.*, 2014).

Limitations and future research

The results and conclusions drawn from this study will provide invaluable information not only for pet dog owners, but for future researchers who wish to build on these findings. However, the author acknowledges the presence of some limitations within this study in order for others to build on these and provide essential future research.

Due to the time restraints within this study, only 30 dogs were included. While Ker and Ramalingam (2013) deemed this sufficient as the sample is significantly larger than other studies (Laverack *et al.*, 2021; Wiener and Haskell, 2016), the author identifies that a larger sample size would allow for investigation into the morphological differences between breeds (Carlisle *et al.*, 2019; Hecht *et al.*, 2019). This would allow for more specific harness recommendations for owners based on individual breed conformation (Voss *et al.*, 2011).

Due to the nature of a university setting, flexibility in study site was required. The author does not feel this affected the results; however, future studies should ensure site consistency (Desai, 2020). Although this study considered harness fitting and possible reactions to the researcher in the pre-trial questionnaire, it did not preassess the dogs' comfort level or experience of being walked on the lead by a stranger. To ensure ethicality, some dogs were walked by their owners to alleviate anxiety; however, future studies should ensure participants are comfortable with being handled by a stranger as part of the screening questions.

To help ensure reliability of results, the same researcher completed every manual angle measurement. However, as angular data was produced manually, there may be a level of unconscious or observer bias. Tanneberger and Ciupitu-Plath (2017) conclude that existing beliefs can impact the results drawn, as has been discussed above with Zink's (2019) study. To mitigate observer bias, future studies should involve multiple observers, as well as following blinding approaches if possible, meaning the researcher measuring the angle does not know which harness they are assessing. Alternatively, other researchers who are not well-informed in the field of harness study could be involved for angle measurements, so they do not have preconceived opinions on each harness.

Alternatively, markers could be used so Quintic Automatic Angle Measurement can be used, which may increase reliability (Engelsman *et al.*, 2022). If markers are used in future research, limitations with this technique such as lacking visibility on thick-furred dogs or movement alterations caused by the markers must be accounted for (Torres *et al.*, 2013).

The inclusion of other gair parameters, such as stride length, would strengthen these findings further (Torres *et al.*, 2017). Size difference and breed conformation impacts stride length, which could influence extension and flexion, so inclusion would add further clarity (Bliss *et al.*, 2022). Furthermore, comparisons of different gaits (e.g. hindlimb angles, or dogs at a trot) would provide further results. This would be especially relevant when researching the long-term effects of harnesses, as pet dogs vary their gait during standard walks (Kano *et al.*, 2016).

Longitudinal studies exploring the correlation between harness design and use and musculoskeletal disorders will help inform harness choices. Ethical considerations must be made here, as this study has shown the potential biomechanical influences of some harness designs (Murray *et al.*, 2021).

A final recommendation for future researchers is the consideration of a larger array of harnesses and brands available to pet owners. Analysis of the different styles within brands (e.g. the Julius K9 straight front and y-front), different brands within styles (e.g. Ruffwear y-front and Julius K9 y-front) and differing the attachment point (e.g. front clip and back clip) would deepen the understanding of harnesses and biomechanics. Focus on brands more/less readily available may result in shifts in the market, improving the knowledge of owners and widening their harness choices.

Despite the aforementioned limitations and requirements for future research, the results of this study are still valid and beneficial for the canine industry as a whole and provides the building blocks for students and researchers to study further into this field. Providing an accessible version for owners will impart clarity and enable them to make informed decisions. Hopefully, these results will drive the future of harness production to ensure for maximum safety and comfort for all dogs.

Conclusion

This study has concisely demonstrated that the choice of pet dog harness impacts biomechanics, closing the research gap into harness impact on canine flexion and extension in pet dogs. The results display the impact of each via angulation and have demonstrated how different harness styles impact shoulder and elbow extension and flexion.

Comparing results of all six harnesses, this study can confidently recommend the Julius K9 straight-front harness or the Halti y-front harness as the preferred option for pet owners. Furthermore, the highly regarded Ruffwear front-clip harness exhibited the largest impact on joint flexion and extension overall, thus

illustrating its unsuitability. The author notes that while these harnesses were graded on suitability in results, the aim was not to conclude 'the best' harness overall; owners must use the information to select the best-suited harness for their individual dog.

Careful analysis of previous studies has allowed this study to accurately improve on previous limitations and draw updated conclusions on their findings. The study has demonstrated a need for further research to assess the impact of harness width on canine biomechanics. Research into breed differences will also help expand this area further.

These findings provide long-term benefits to the pet dog community. The inclusion of commonly available harnesses means that these conclusions are accessible for the average dog owner, and will help them to make informed decisions on their dogs' safety and wellbeing. This also provides appropriate alternatives and reassurance for those dogs for whom a collar is unsuitable.

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Finally, to the wonderful owners of the dogs included in my study!

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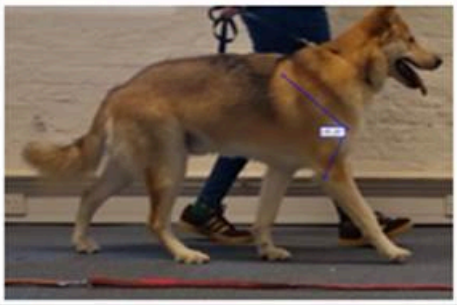
Appendix 1

Table A1: Harness brands, names, styles and images.

Harness Brand	Harness Name	Harness Style	Image of Harness
Julius K9	IDC© Powerharness	Straight front	
Ruffwear	Front Range© Dog Harness	Front-range	
EzyDog	Chest Plate Harness	Chest plate	
Halti	Comfort Collar	Base collar	
	No Pull Harness	No-pull	
	Walking Harness	Y-front	
3 Peaks	Step-In Harness	Step-in	

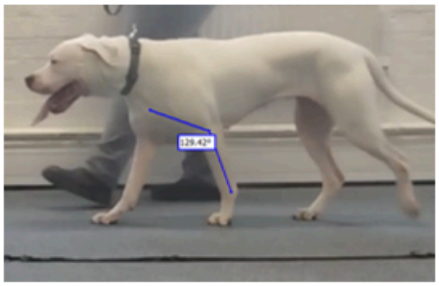
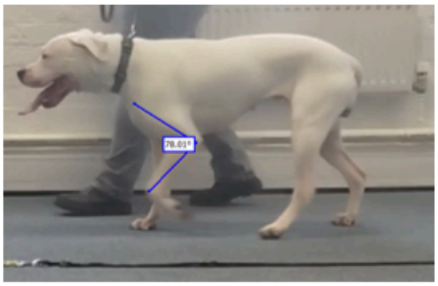
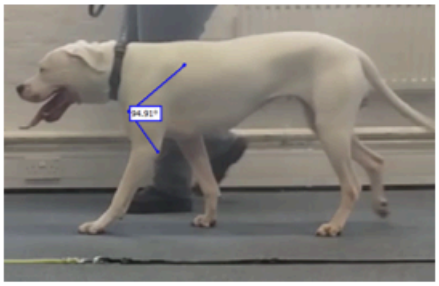
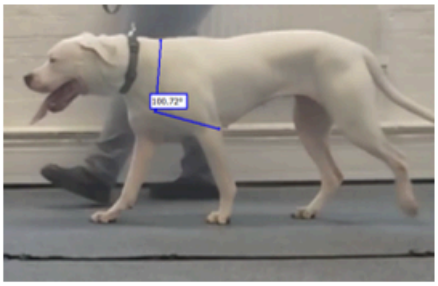
Appendix 2

Table A2: The four gaits measured

Elbow Extension	Elbow Flexion
	
Shoulder Extension	**Shoulder Flexion**
	

Appendix 3

Table A3: The four gaits measured

Elbow Extension	Elbow Flexion
	
Shoulder Extension	**Shoulder Flexion**
	

Appendix 4

Normality Tests for each harness/angle combination (28 in total)

This supplementary material provides the results from all 28 normality tests performed for each harness/angle combination. Although an omnibus normality test was performed overall, the individual results are concluded for additional information. The following table summarises the test statistics and p-values for each combination (all were analysed using a Shapiro-Wilk normality test).

Table A4: Normality tests performed for each harness/angle combination

Angle	Harness	Test Statistic (W)	P-Value	Comments
Elbow Extension	Base Collar	0.96129	p<0.01	Non-normal
Elbow Extension	Straight Front	0.96393	p<0.05	Non-normal
Elbow Extension	Front Clip	0.98338	p>0.1	Normal
Elbow Extension	Chest Plate	0.98373	p>0.1	Normal
Elbow Extension	Y-Front	0.97280	p>0.05	Normal
Elbow Extension	No-Pull	0.98833	p>0.1	Normal
Elbow Extension	Step-In	0.98822	p>0.1	Normal
Elbow Flexion	Base Collar	0.98283	p>0.1	Normal
Elbow Flexion	Straight Front	0.98947	p>0.1	Normal
Elbow Flexion	Front Clip	0.98160	p>0.1	Normal
Elbow Flexion	Chest Plate	0.96669	p<0.05	Non-normal
Elbow Flexion	Y-Front	0.98364	p>0.1	Normal
Elbow Flexion	No-Pull	0.97726	p>0.1	Normal
Elbow Flexion	Step-In	0.97162	p<0.05	Non-normal
Shoulder Extension	Base Collar	0.98547	p>0.1	Normal
Shoulder Extension	Straight Front	0.98047	p>0.1	Normal
Shoulder Extension	Front Clip	0.97633	p>0.05	Normal
Shoulder Extension	Chest Plate	0.97865	p>0.1	Normal
Shoulder Extension	Y-Front	0.96099	p<0.01	Non-normal
Shoulder Extension	No-Pull	0.97347	p>0.05	Normal
Shoulder Extension	Step-In	0.98783	p>0.1	Normal
Shoulder Flexion	Base Collar	0.98368	p>0.1	Normal
Shoulder Flexion	Straight Front	0.98531	p>0.1	Normal
Shoulder Flexion	Front Clip	0.98815	p>0.1	Normal
Shoulder Flexion	Chest Plate	0.97574	p>0.05	Normal
Shoulder Flexion	Y-Front	0.98522	p>0.1	Normal
Shoulder Flexion	No-Pull	0.99054	p>0.1	Normal
Shoulder Flexion	Step-In	0.98246	p>0.1	Normal

The normality tests indicate that although the majority of the data had a normal distribution, some were non-normally distributed showing significant deviations.

Appendix 5

Kruskal Wallis with pairwise Wilcox post-hoc for elbow extension

Due to there being non-normal data in the elbow extension results, a non-normal pairwise test is required, which is why a Kruskal Wallis with pairwise has been chosen. This shows comparisons between each collar/harness type.

Table A5: Comparisons between each collar/harness type using a Kruskal Wallis with pairwise (chi-squared = 28.57, df = 6, $p<0.001$)

	Base Collar	Str. Front	Front Clip	Chest Plate	Y-Front	No-Pull
Str. Front	1.00000	-	-	-	-	-
Front Clip	0.00295	0.00507	-	-	-	-
Chest Plate	1.00000	1.00000	0.00141	-	-	-
Y-Front	1.00000	1.00000	0.00339	1.00000	-	-
No-Pull	0.48788	0.74240	0.48788	0.48788	0.73307	-
Step-In	0.00166	0.00082	1.00000	0.00022	0.00070	0.17544

Appendix 6

Kruskal Wallis with pairwise Wilcox post-hoc for elbow flexion

Due to there being non-normal data in the elbow flexion results, a non-normal pairwise test is required, which is why a Kruskal Wallis with pairwise has been chosen. This shows comparisons between each collar/harness type.

Table A6: Comparisons between each collar/harness type using a Kruskal Wallis with pairwise (chi-squared = 42.87, df = 6, $p<0.001$)

	Base Collar	Str. Front	Front Clip	Chest Plate	Y-Front	No-Pull
Str. Front	1.00000	-	-	-	-	-
Front Clip	0.00073	0.05569	-	-	-	-
Chest Plate	0.54035	1.00000	0.07444	-	-	-
Y-Front	1.00000	1.00000	0.00307	1.00000	-	-
No-Pull	0.01488	0.54035	1.00000	0.87149	1.00000	-
Step-In	0.63946	1.00000	0.23166	1.00000	1.00000	1.00000

Appendix 7

Kruskal Wallis with pairwise Wilcox post-hoc for shoulder extension

Due to there being non-normal data in the shoulder extension results, a non-normal pairwise test is required, which is why a Kruskal Wallis with pairwise has been chosen. This shows comparisons between each collar/harness type.

Table A7: Comparisons between each collar/harness type using a Kruskal Wallis with pairwise (chi-squared = 50.89, df = 6, $p<0.001$)

	Base Collar	Str. Front	Front Clip	Chest Plate	Y-Front	No-Pull
Str. Front	0.20795	-	-	-	-	-
Front Clip	5.4e-06	0.00570	-	-	-	-
Chest Plate	0.00078	0.22826	1.00000	-	-	-
Y-Front	0.20795	1.00000	0.04041	0.51661	-	-
No-Pull	4.3e-06	0.01594	1.00000	1.00000	0.02093	-
Step-In	1.2e-05	0.02711	1.00000	1.00000	0.12960	1.00000

Appendix 8

One-Way ANOVA with Tukey's honest significant difference (HSD) test for shoulder flexion

Shoulder flexion had normal data for all harnesses/collars. Due to this, a normal pairwise test is required, which is why a One-Way ANOVA with Tukey's HSD test has been chosen. This shows comparisons between each collar/harness type.

Table A8: Comparisons between each collar/harness type using a Tukey's HSD test ($F = 9.02$, df = 6, $p<0.001$)

	Base Collar	Str. Front	Front Clip	Chest Plate	Y-Front	No-Pull
Str. Front	0.60419	-	-	-	-	-
Front Clip	0.00000	0.00016	-	-	-	-
Chest Plate	0.01801	0.69844	0.05449	-	-	-
Y-Front	0.15977	0.98634	0.00411	0.98594	-	-
No-Pull	0.00000	0.00437	0.98472	0.33900	0.05646	-
Step-In	0.00898	0.56080	0.09482	0.99999	0.95470	0.46886

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Glossary

Asymmetry: A lack of symmetry; differences in the behaviour of the limbs during movement.

Biomechanical: The study of mechanics and movement or structure of living organisms.

Brachycephalic breeds: dog breeds with flat faces and shortened snouts, which can lead to health problems.

Conformational disorders: Animals with exaggerated body shape, structure or appearance, which can negatively impact their health and welfare.

Gait: The pattern of steps of an animal at a certain speed or pace.

Gait analysis: the measurement of how the body moves during locomotion.

Generalised Linear Mixed Model (GLMM): a statistical regression model which is able to include randomeffects from different distributions.

Habituation: The decreased response to a certain stimulus after repeated exposure.

Kruskal Wallis: a nonparametric test which is rank-based which tests to see if there are statistical significant differences between two or more groups.

Longitudinal studies: A study that takes place over a long period of time; subjects are followed over time with either continuous or varied monitoring to see long-term impacts.

Markers: Reflective markers are placed on the subject; these are then tracked by cameras and used to create a 3D model of the subject's movement.

Morphological: Refers to the size, shape and structure of the body.

Non-restrictive harness: A harness that does not restrict movement.

Peak vertical force: The maximum force exerted perpendicular to the surface during stance phase.

Post-hoc test: A test used to analyse the results of an experiment with more than two groups to identify where the differences lie between the groups.

Restrictive harness: A harness that restricts movement in some way.

Straight front harness: this type of dog harness has a single, usually thick strap that goes horizontally across the dog's chest.

Tukey honest significant difference post-hoc: a test to see the significant differences between different groups.

Y-front harness: this type of dog harness has y-shaped straps that runs between the dog's front legs over the shoulder.

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Prevalence of Clinical and Subclinical Cattle Mastitis and the Associated Risk Factors in Bomet County, Kenya

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Abstract

A survey of mastitis in cattle was conducted in Bomet County of Kenya, using the California mastitis test (Pyörälä *et al.*, 2003). A total of 75 bovines from 50 farms were sampled and the overall cow level prevalence of mastitis was 16 per cent. Out of the 75 bovines sampled, the prevalence of clinical and subclinical mastitis was 4 per cent and 12 per cent respectively. In the intensive system of livestock production, the prevalence was 13.3 per cent, while in the semi-intensive system of livestock production, the prevalence was 2.7 per cent. A questionnaire was also completed by 50 farmers to collect data on risk factors, which included udder hygiene, stage of lactation, parity and floor type of cow housing, breeds (among the breeds, Friesians had a higher prevalence than Ayrshire breeds). This study showed that penicillin and streptomycin (40 per cent) were the most used drug to treat mastitis. In conclusion, the overall prevalence could have been attributed to poor milking practices and inadequate methods applied by farmers in controlling mastitis on their farms due to lack of knowledge as noticed from the discussions with the farmers on mastitis control guidelines (Kerro Dego *et al.*, 2020).

Keywords: Bovine mastitis in Bomet County, California mastitis test, Lactation, Milking practices and mastitis.

Introduction

Dairy is the most important and single largest agricultural sub-sector in Kenya, contributing 19 per cent of the agricultural GDP and 3.5 per cent of the total GDP (Muriuki *et al.*, 2004). A cow in Kenya produces an average of 7–8 litres daily with production of between 2000 and 2400 litres per lactation. The productivity is low compared to 60 litres daily in developed countries such as United States of America which is leading productivity per cow with an average of 14,000 litres per lactation (Wambugu *et al.,* 2011). This low milk production can be attributed to various constraints – among them, animal diseases, poor genetics, poor food quality and quantity, and fluctuating seasonal forage availability (Muriuki, 2011). The most reported animal disease is mastitis, which refers to inflammation of mammary glands (Ndirangu *et al.*, 2019). It is characterised by physical and chemical changes in milk and pathological changes in the gland (Bortolami *et al.*, 2000). The occurrence of mastitis is attributed to interplay of three major factors that include: infectious agents, environment and hosts (cows). It is multi-etiological and caused by several species of bacteria, algae and fungi. However, bacteria causes the majority of mastitis infections and these include *Staphylococcus* spp, *Streptococcus* spp and *Escherichia coli* (Ndirangu *et al.*, 2017; Ndirangu *et al.*, 2022). Mastitis is a global problem because of its adverse effects on animal health, animal welfare because mastitis causes a lot of pain in cows (Suárez *et al.*, 2017), quality of milk and the huge financial losses it causes.

In Kenya, the prevalence of clinical mastitis has been reported by Nkoroi *et al.* (2014), who reported a prevalence of 87.4 per cent and Ndirangu *et al.* (2022) a prevalence of bovine subclinical mastitis of 33 per

cent in Kenya. Bovine subclinical mastitis refers to an inflammatory reaction of the udder tissue in dairy cows without showing obvious clinical signs such as abnormal milk or swollen udders. It is characterised by increased somatic cell counts in milk which indicates an immune response to infection. Mastitis is the single most important production disease – for example, in Ethiopia it has been reported to cause a loss of US$38 per cow per lactation (Mungube *et al.*, 2005) due to the negative impacts that include reduced milk yield, unwanted changes in milk composition and increased cost of medicine and veterinary services (Ayano *et al.*, 2013). It is a great constraint to the development of profitable dairy enterprises, particularly in developing countries like Kenya in which the dairy industry plays a big role in the livelihood of the farmers who rely on the income from the milk sold. This therefore necessitates the application of mastitis control programmes (Kerro Dego *et al.*, 2020). Studies by Kivaria *et al.* (2006) stated that one of the major concerns related to mastitis in Tanzania is that farmers and herd attendants needed to improve their knowledge, attitude and motivation towards udder health. Nkoroi *et al.* (2014) reported that the only measures adequately embraced in Mathira (Nyeri County) were treatment of clinical mastitis and sanitation. Studies by Omore *et al* (1999) stated that mastitis control strategies that should be done includes dry cow therapy and use of strip cups to test mastitis during milking. Flies increase the risk of mastitis in dairy cows by transmitting bacteria via their mouthparts during feeding on teat wounds, leading to Intrammary infections; therefore, there are a number of ways to control flies on dairy farms. These include: sanitation, fly traps, fly repellents, biological control preventing manure from accumulating, eliminating standing water and maintaining good pasture management (Watson *et al.*, 1994).

Previous unpublished reports from Bomet sub-county veterinary office indicated an average of 70 cases of both clinical and subclinical mastitis monthly. Therefore, factors contributing to this observation needed to be identified so as to reduce its prevalence and hence decrease reduced milk yield, milk spoilage and increased costs of medicine and veterinary services (Ayano *et al.*, 2013) and improve animal welfare. This information would also be used to come up with an appropriate mastitis control programme that could then be disseminated. Knowledge about the prevalence, associated risk factors and the level of application of various mastitis control measures is needed for successful management and control of mastitis, which would thus prevent losses incurred as a result of mastitis

This study was coined to determine prevalence of clinical and subclinical mastitis in dairy cattle using the California mastitis test in Bomet County (Pyörälä *et al.*, 2003). This study further sought to establish whether farmers have information about other available mastitis control measures, to determine how efficiently they are applied and to consider challenges that farmers face in the application of mastitis control measures.

Materials and methods

Study area

This study was undertaken in Bomet County, which is located between latitudes 0°29 and 1° 03 south and between longitudes 35° 05 and 35 35 east (Figure 1). The county was selected due to its predominantly agricultural nature, with dairy farming being a major enterprise.

Bomet County had a population of 875,689 in 2019 and covers an area of 1630.0 km^2. It experiences a warm and temperate climate with an average temperature of 17.7°C. The average annual precipitation is approximately 1461 mm (57.5 inches) (Kenya Independent Electoral Boundaries Commission, 2012).

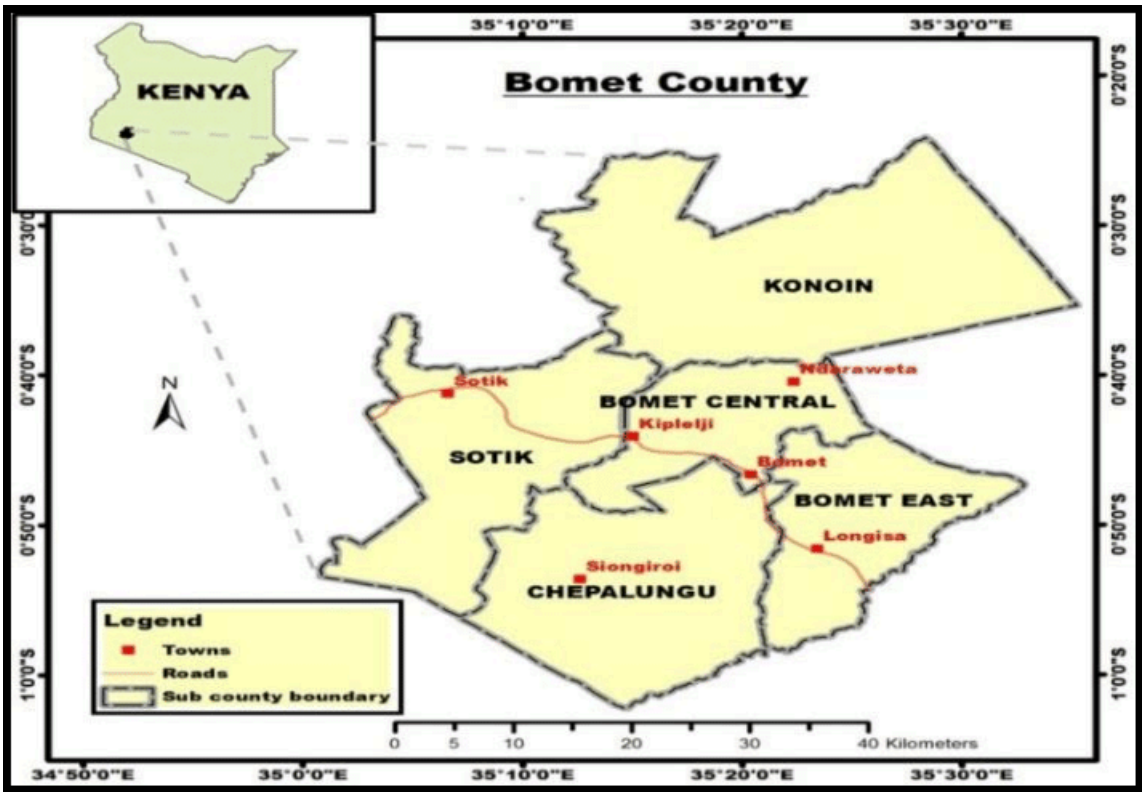

Figure 1: Map of Bomet County (Kenya Independent Electoral and Boundaries Commission, 2012)

Study design

A purposive survey method using a semi-structured questionnaire administered at farm level was used to collect data on mastitis management practices (survey questions in the appendix section), knowledge on mastitis control measures and challenges that the farmers faced. Further, prevalence of clinical and subclinical mastitis was determined at cow level using the California mastitis test (CMT) in the following steps: Prior to milk sample collection, the teats of lactating cows were washed with water and then wiped with cotton wool dipped in 70 per cent alcohol disinfect. About 2 millilitres of milk from each teat of the lactating cow was milked directly onto the corresponding cup/well of the CMT paddle and an equal amount of 3 per cent CMT reagent added to each cup and mixed well. Supplementary data was also collected through observation and discussion with owners/managers and milkmen/herdsmen. A total of 50 smallholder farmers were included.

Study population

The study surveyed 75 lactating cows, where 14 cows were managed under complete zero grazing and 61 under semi-intensive systems. The cows under study had varying parity of between one and three calves, and more than three calves, the stages of lactations were 1–2 months, 3–6 months and more than 7 months of lactation. The breed under study were Friesian and Ayrshire.

Detection of clinical and subclinical mastitis

Lactating cows were examined for clinical mastitis by udder inspection or palpation and visual examination of milk for any changes. The udders were visually inspected for change in shape, swellings and palpated for abnormal lesions and the consistency of the udder was felt. The milk was also checked for flakes, clots and

other abnormalities. Subclinical mastitis was detected by testing milk samples using the California mastitis test as described by Quinn *et al.* (1999).

The nature of coagulation and viscosity was then examined after 15–30 seconds to detect the presence and severity of the mastitis infection. The results were then scored based on the gel formation: negative meant no gel formation and trace, or positive when there was gel formation and this categorised as +1, +2 and +3 as described by Quinn *et al.* (1999). The California Mastitis testing was carried out during milking time under natural light conditions to get correct results interpretation. See Table 1 and Figure 2.

CMT Scale	Interpretation	Observation
0	Negative	No gel formation
1	Trace–weak positive	Slight precipitation to distinct precipitation with weak gel formation
2	Weak positive–distinct positive	Distinct precipitation mixture thickness with gel formation
3	Strong positive	Strong gel formation which is cohesive with a concave surface

Table 1: CMT scale and their respective interpretation Quinn *et al.* (1999).

Figure 2: Showing results of California mastitis test (from the author's own collection).

Collection of data on farmer's knowledge, mastitis control methods and challenges in controlling mastitis

A semi-structured farm-level questionnaire was administered to 50 farmers in the study area. Additional information was obtained through personal observations and discussions with the farmers. The farmers were interviewed in Kiswahili and Kipsigis languages.

Data management and analysis

The questionnaire data was collected and CMT test results was entered into an MS-Excel data sheet for analysis. Descriptive statistics were generated where prevalence was calculated as number of animals positive for mastitis divided by total number of animals tested. These were calculated for different cattle breeds, grazing system and lactation period. The results were finally summarised into tables and figures.

Results

Characteristics of study animals and their grazing and/or management systems

A total of 50 dairy cattle farms were included in the study. Out of these, six farms practised complete zero grazing while 44 farms practised a semi-intensive management system (12 and 88 per cent) respectively. A total of 75 lactating cows in varying parities were included where 36 were under zero grazing units and 39 were from semi-zero grazing dairy fenced cattle units. The cows were between 1 and 6 months of lactation. The exotic dairy breeds under study were Friesian 39 (52 per cent) and Ayrshire 36 (48 per cent).

Prevalence of mastitis overall

As shown in Table 2, the overall prevalence of mastitis was 12/75 (16 per cent); where 3/75 (4 per cent) had clinical mastitis showing signs such as pus and clots in milk, painful, swollen, hardened udders, and 9/75 (12 per cent) had subclinical mastitis (were CMT positive).

CMT Results	No of cows (n = 75)	Prevalence (%)
CMT Positive	12	16
CMT Negative	63	84

Table 2: Prevalence of mastitis in Bomet County, Kenya (n = 75).

Prevalence of mastitis in intensive and semi-intensive systems

The prevalence of mastitis in intensive farms in this study is higher in farms that practised intensive farming compared to those who practised semi-intensive farming.

Production system	Number of farms (n = 50)	Percentage %
Intensive	6	12
Semi-intensive	44	88

Table 3: Percentage herd size distribution of the farms under study based on production system (n = 50).

Prevalence of mastitis at udder quarter level and CMT scores

Milk samples from seven cows with a total of 28 quarters showed slight precipitation to distinct precipitation with weak gel formation (trace – weak positive), milk from two cows (total of 8 quarters) showed distinct precipitation mixture thickness with gel formation, milk from three cows (total of twelve quarters) showed strong gel formation that was cohesive with a concave surface (strong positive), as shown in Table 4.

CMT scale	Number of quarters that were CMT positive	No of cows who were CMT positive	Total number of quarters for all animals studied	Total no of animals
1	28	7		
2	8	2		
3	12	3		
Total	48	12	300	75

Table 4: Prevalence of mastitis at udder quarter level and CMT scores.

Prevalence of mastitis in relation to breed, age, milk production, parity management system, udder hygiene, stage of lactation and floor type

Analysis for prevalence of mastitis were based on breed, age, parity, production system, udder hygiene, stage of lactation and floor type revealed that mastitis was mostly associated with breed, age group, milk production, udder hygiene, stage of lactation, floor type, production system and parity. Further, high prevalence of the disease was noted in earthen floors, those cows with dirty udders and in cows 3–6 months of lactation. Out of the 75 bovines sampled, Friesian breeds (n=39) had a positive prevalence of seven cows (9.3%; n=75) compared to Ayrshire breeds (n=36) with a positive prevalence of five cows (6.7%; n=75) cows with mastitis. Of those cows with one to three calves (n=43), four cows (5.3%; n=75) were positive for mastitis, while those with more than three calves (n=32), eight cows (10.7%; n=75) were positive for mastitis. Results based on the production system (intensive: n=14; semi-intensive: n=61), showed that ten cows (13.3 %; n=75) were positive for mastitis from intensive system and two cows (2.7%; n=75) of the positive cases were from semi-intensive farms. The results based on stage of lactation shows cows with more than 7 months lactation period (n=45) with mastitis were three cows (4%; n=75) while cows within 3–6 months (n=8) with mastitis were four cows (5.3%; n=75). Those within 1 to 2 months stage of lactation (n=22) with mastitis were five cows (6.7%; n=75). Based on the floor type, the prevalence of mastitis was higher in cows housed in stalls with earthen floors (9 cows, 8 with mastitis = 10.6%) compared to those with concrete floors (5 cows, 2 with mastitis, = 2.6%).

Additionally, the prevalence of mastitis was significantly higher in cows older than 6 years (n=18). This was nine cows with mastitis (12%; n=75) compared to cows less than 6 years of age (n=57). This was three cows (4%; n=75).

Breed	Total number of cows (n=75)	CMT positive	%
Friesian	39	7	9.3
Ayrshire	36	5	6.7

Parity	Total number of cows (n=75)	CMT positive	%
1–3 calves	43	4	5.3
Fewer than 3 calves	32	8	10.7

Production system	Total number of cows (n=75)	CMT positive	%
Intensive	14	10	13.3
Semi-intensive	61	2	2.7

Stage of lactation	No of cows (n=75)	CMT positive	%
>7	45	3	4
3 to 6	8	4	5.3
1 to 2	22	5	6.7

Floor type	No of cows	CMT positive	%
Concrete	5	2	2.6
Earthen	9	8	10.6

Age	No of cows	CMT positive	%
< 6yrs	57	3	4
>6yrs	18	9	12

Stage of lactation	Total no of cows	CMT positive	%
1–2 months	**9**	**2**	**2.6**
3–6 months	**24**	**8**	**10.6**
>7	**42**	**2**	**2.6**

Table 5: Prevalence of mastitis in relation to breed, age milk production, parity management system, udder hygiene, stage of lactation and floor type.

Survey results

Farmer's knowledge and practices in relation to control of mastitis

A very small number of farmers (15 out of 50; 30%) farmers had undergone training in dairy cattle husbandry and had acquired dairy cattle management skills such as sanitation and hygiene, good milking practices, mastitis prevention and treatment. However, all farmers had knowledge about mastitis. The farmers who had not undergone dairy cattle husbandry training and knew about mastitis had known about it from other farmers and veterinarians. Of the farmers interviewed, 80 per cent checked for mastitis during milking time by looking for changes in milk and udder (96.4%) and by use of a strip cup (6%); however, only 6 per cent knew about subclinical mastitis. In addition, 38 per cent of the farmers had experienced cases of mastitis and 12 per cent of those farmers had been involved in treating the cases themselves. Only 6 per cent of the farmers tested the milk sample before treatment. All the farmers considered mastitis as the major production constraint and all hand milked their cows.

Feature	Number		Total	Percentage	
	Yes	No			
Trained in dairy cattle husbandry	15	35	50	30	
Know about mastitis	50	0	50	100	
Check for mastitis	3	47	50	6	
Changes in udder and milk					
Use of the strip cup	3	47	50	6	
Ever had mastitis	19	31	50	38	
Treated mastitis cases	50	0	50	100	
Respond to therapy	31	19	50	72	
Dry therapy	1	49	50	2	
Use of teat dips	1	49	50	2	
Drying the udder after washing	8	42	50	16	
Personnel who treated such cows					
Veterinarian	13			76	
Animal health assistant	2			12	
Self-treated by farmer	2			12	
Awareness of subclinical mastitis	Yes	No		Yes %	No %
Total (n=50)	3	47		6	94

Table 6: Farmer's knowledge and practices in mastitis control.

Methods applied in mastitis control

The majority of the farmers (70%) practised good hygiene, both within the cow sleeping area and milking parlour as a preventive measure. When considering hand-washing, all 50 farmers washed their hands. However, only 24 per cent of the farmers used heated water and only 77 per cent washed hands between milking. Only 16 per cent farmers used towels to clean the udder, and none had culled cows as a result of mastitis cases. One farmer used teat dips while the others did not use it due to lack of knowledge of the availability of this method. Only one farmer utilised the dry cow therapy control method for mastitis, while others employed disinfectants and detergents. The low adoption rate of dry cow therapy was attributed to both a lack of knowledge and the associated costs.

Method	Number	Per cent
Hygiene	35/50	70
Hand washing	50/50	100
Udder washing	50/50	100
Use of towels	8/50	16
Use of teat dips	1/50	2
Treatment of clinical cases	18/18 sick cows	100
Dry cow therapy	1/50	2
Culling	0/50	0
Use of disinfectants/detergents	1/50	2
Use of hot water during hand washing	12/50	24
Wash hands between milking	40/50	77

Table 7: Methods applied in mastitis control.

The cows that had clinical signs were treated using penicillin and streptomycin (40%) while gentamycin was used the least (8%). While 36 per cent knew about intra-mammary infusions. Another 16 per cent of the farmers were not aware which antibiotic had been administered (Figure 3).

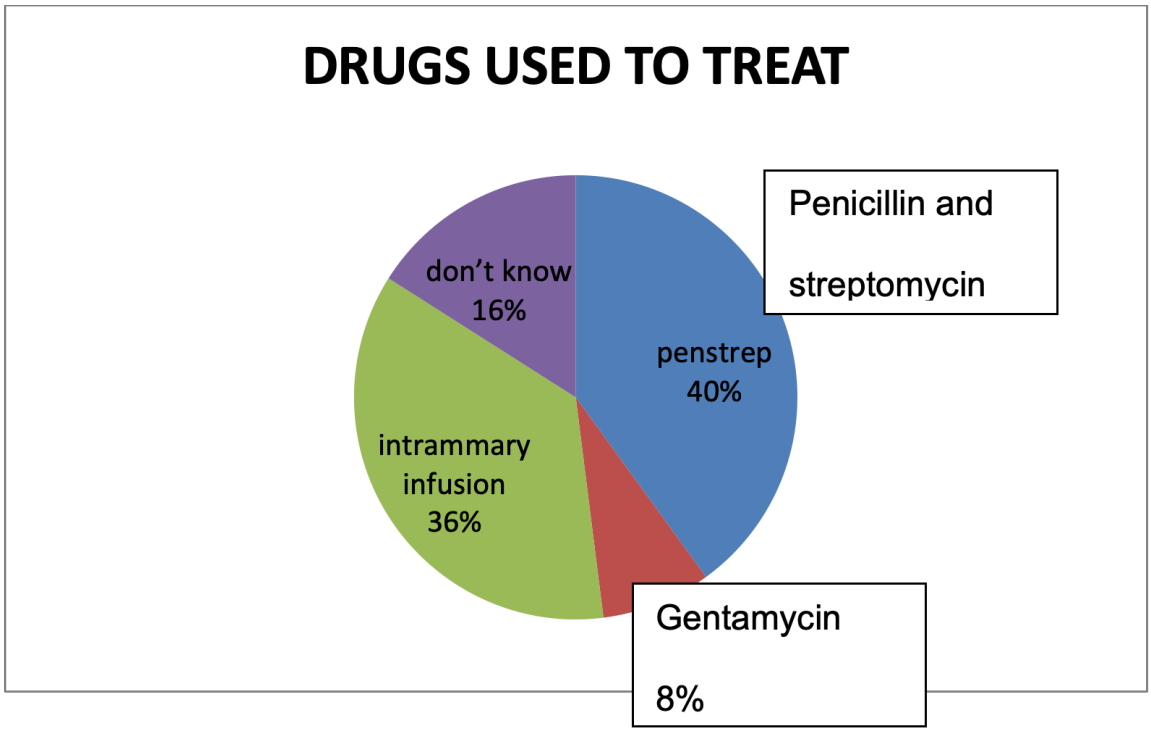

Figure 3: Antimicrobials used to treat clinical cases (route-IM). Intra-mammary infusion constituents (Penicillin G ampicillin).

Challenges faced by farmers in mastitis control

Maintenance of good hygiene and high treatment costs were the biggest challenges that farmers were facing in control of mastitis. Difficulty in maintaining good hygiene was associated with poor floors because some were earthen and even those that were concrete had holes that contained dirty water and urine.

Discussion

The study indicated an overall prevalence of 16 per cent as determined by CMT screening at cow level. The prevalence is lower as compared to eight other previous studies that were done between 2011 and 2021 using California mastitis test by Sarba and Tola (2017), Gitau *et al.* (2014), Gutu *et al.* (2021), Mbindyo *et al.* (2020), Mureithi and Njuguna (2016), Nkoroi *et al.* (2014) and Ondiek and Kemboi (2018) (summarised in Table 8). This indicates that mastitis control programmes in Bomet central sub-county are effective compared to studies done in Embu and Kajiado counties (Mbindyo *et al.*, 2020) and Thika sub-county (Mureithi and Njuguna, 2016). This improvement could be due to improved management skills because 30 per cent of the farmers had attained training in dairy cattle husbandry as compared to 3.9 per cent reported by Nkoroi *et al.* (*2*014). Further all the farmers considered mastitis as a major production constraint, hence they have applied preventive measures such as good hygiene, udder and husbandry hygiene among other practices such as dry cow therapy. This low prevalence could be partly attributed due to low number of sample size as compared to other studies; however, research can be done to reduce incidence by support and education to farmers on control of mastitis with the aim of reducing this prevalence below 16 per cent.

	Current study 2022	Gutu*et al.*, 2021	Mbindyo *et al.*, 2020	Ondiek and Kemboi, 2018	Sarba and Tola, 2017	Mureithi and Njuguna 2016	A`bebe *et al.* 2016	Gitau *et al.*, 2014	Nkoroi *et al.*, 2014
Sample size	75	110	400	41	302	172	529	241	202
Prevalence (%) of mastitis	16	39.67	80	34	41.7	64	76	30	87.9

Table 8: Prevalence of mastitis in current and previous studies.

The prevalence of mastitis in intensive units recorded a high prevalence of 13.3 per cent per cent (n=75) compared to semi-intensive units with a prevalence of 2.7 per cent (n=75) (summarised in Table 5). These findings agree with those of Ait-Kaki *et al.* (2019), Sarba and Tola (2017) and Sori *et al.* (2005), but differ from the study done by Senthilkumar *et al.* (2024) who reported a higher prevalence in semi-intensive farms than the intensive farms. This is expected because intensively managed cows are at a higher risk of the development of mastitis than semi-intensive. The prevalence of mastitis in intensive and semi-intensive system depends on the effectiveness of control methods applied.

Production system	Current study-2022	Asma *et al.* 2019	Sarba and Tola 2017	Mpatswenumugabo *et al.* 2017	Senthilkumar *et al.* 2024	Sori *et al.* 2005
Intensive farms	13.3%	27.8%	42.3%	61.3%	14.06%	37%
Semi-intensive farms	2.7%	21.2%	8.1%	38.7%	36.73%	21.2%

Table 9: Prevalence of mastitis in the current and previous studies based on the farming systems.

From further discussions with the herdsman, 10 per cent of the units revealed that there was no regular cleaning of the units on daily basis, between milkings and weekly

In this study, the prevalence of subclinical mastitis was 12 per cent (n=75), while the prevalence of clinical mastitis was 4 per cent (n=75). These findings were lower than those reported by Mbindyo *et al.* (2020) who reported subclinical mastitis as 74 per cent, while clinical mastitis as 6.8 per cent in Embu and Kajiado counties. Ndahetuye *et al.* (2020) reported 76.2 per cent cases of subclinical mastitis in Rwanda; Mureithi and Njuguna (2016), reported subclinical mastitis as 64 per cent in Thika, Kenya. All of the farmers washed their hands before milking, although 24 per cent of them used unheated water, and 77 per cent washed hands between milking hence minimising transfer of pathogens from cow to cow. In addition, none of the farmers culled chronic mastitis cases. Most of the farmers milked the sick cows last as a preventive measure. Kivaria *et al.* (2006) reported that poor practices such as milking mastitic cow's first leads to spread and sustains mastitis in herds, which then becomes very difficult to be eliminated from the herd. Further, 16 per cent of farmers used a towel for drying the udder, and this might have contributed to reduced spread of mastitis from one animal to another.

This study indicated that Friesian had a higher prevalence than Ayrshire cows of 9.3 per cent and 6.7 per cent respectively (Table 5). This study showed that breed had an influence of the prevalence of mastitis within the population tested, this agrees with the studies done by Islam *et al.* (2011). However, it disagrees with the findings of Mureithi and Njuguna (2016) who found that Ayrshire had the highest prevalence of 80.6 per cent compared to 71.7 per cent of Friesians. The influence of breed on mastitis prevalence can be related to anatomical and the physiological features of the mammary gland of a particular breed which then predisposes it to mastitis (Ameh *et al.*, 1999).

The hind quarters were more prone to infections as compared to fore-quarters and this might be due to anatomical locations of the hind quarters thus predisposing them more to infections (Choudhary and Kashyap, 2019).

All the farmers knew about mastitis and considered mastitis to be a major production constraint and of major concern in animal welfare. This could be partly attributed to the fact that 30 per cent of the farmers had attained training in doing cattle husbandry as compared to the 3.9 per cent seen by Nkoroi a decade earlier (2014) However only three farmers (6%) knew of subclinical mastitis.

This study indicated that good hygiene was practised by a large number of farmers (70%), and this included the cow's environment hygiene and milking hygiene as it is recommended by Wallace *et al.* (2004) to prevent new intra-mammary infections. In addition, treatment of clinical cases represented another significant aspect of their practices, in accordance with Nkoroi *et al.* (2014), who noted that sanitation and clinical case treatment were the two primary practices implemented. Only 2 per cent of farmers used dry cow therapy, while 16 per cent used towels. Notably, none of the farmers utilised teat dips. These practices could have influenced the observed prevalence.

There are variations in the challenges that farmers faced in controlling mastitis and, in this study, maintenance of good hygiene practices – which includes proper hygiene, clean structures, clean milking processes, gentle and proper handling and proper milking techniques – treatment of clinical mastitis was a major challenge. Poor practices in mastitis control and hygiene were a problem because of poor flooring and poor access to water source in some farms, overuse of antibiotics, improper milking techniques, inadequate sanitation, overcrowding and poor ventilation. Some farms had poor floors with potholes that contained pools of dirty water, while others had no drainage system. Even those with drainage systems were poorly constructed and contained stagnant dirty water. The majority of the farmers (94%) knew nothing about subclinical mastitis. This perhaps explains why treatment was the second most used method in dealing with mastitis. It can be seen that lack of knowledge on subclinical mastitis may explain the inadequate application of preventive measures. The high costs of treatment could be partly related to the fact that the major antibiotic being used is penicillin and streptomycin (40%) while gentamycin was the least used (8 per cent). However, studies indicate high sensitivity of micro-organisms to gentamycin and Kanamycin and low sensitivity to penicillin, ampicillins, amoxicillin, streptomycin and tetracycline (Gitau *et al.*, 2014). Mugenyi (2014) recorded a sensitivity of 98 per cent for gentamycin in mastitis cases. Other factors that might have contributed to high bacterial resistance – hence the reason why high treatment exists, as observed in this study –could have been lack of testing milk samples before treatment and lack of completing the treatment regime.

Conclusion and recommendations

Conclusion

This study shows that the overall prevalence of mastitis in Bomet central sub-county was 16 per cent. The prevalence of mastitis was higher in intensive farms (13.3 per cent) compared to semi-intensive farms (2.7 per cent). It was found that associated risk factors such as floor type, breed and stage of lactation contributed to the occurrence of mastitis.

Recommendations

The low prevalence of mastitis reported could be due to an effective mastitis control programme in the region; however, there is room for improvement to further lower the prevalence of mastitis in Bomet central.

The prevalence of mastitis in intensive farms 13.3 per cent is higher than semi-intensive farms 2.7 per cent. This necessitates a study of drivers of mastitis in intensive farms with the aim of controlling them.

This study did not look at culture to determine the specific mastitis pathogens in cows in this region, and we recognise this as a limitation of the study – future studies in the region should consider culturing in order to inform better control programmes.

Acknowledgements

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Appendix 1: Questionnaire

Farms survey questionnaire for dairy farmers

Demographic information
Farm no
Name of the respondent
Gender
Telephone Number of respondent
Age
Date of the interview
County
Sub-county
Division
Location
Village
GPS coordinates
Agro-ecological zone (AEZ)

Farm background

1. How many cows do you have?

2. Production system: A) Intensive ___ B) Semi-intensive___

3. How many milking cows do you have? _____

4. Do you keep records? _____ Yes No

If yes, specify a) Production___ b) Breeding___ C) others (specify) _____

5. Have you ever experienced cases of mastitis in the farm? Yes No

6. How long did the mastitis get to resolve?

A. Three days

B. One week

C. Never resolved

7. How did you know the cow had mastitis?

A. Reduced milk production

B. CMT

C. Alcohol test

D. Swollen udder

E. Clots in milk

8. How often in the last one year has mastitis occurred?

Which treatment methods were used?

9. Who treated the animals?

A. A vet

B. Animal health assistant

C. The farmer him/herself

10. What is the average cost of treatment?

11. Does mastitis affect milk production? Yes No

Farm management practices such as:-

1. Are you aware of good farm management practices? (yes or no)

2. Are the cows housed with a roof? (yes or no)

3. If yes what is the floor type made of? (concrete or earthen)

4. Is there bedding for the cows? (yes or no)

5. What is the cleaning frequency? (daily or weekly)

6. Do you do proper milking techniques? (yes or no)

7. Do you milk mastitic cow last? (yes or no)

8. Do you wash the udder before milking? (yes or no)

9. Do you dry the udder after washing? (yes or no)

10. If yes, do you use udder towel for each cow? (yes or no)

11. Do you do routine testing for mastitis? (yes or no)

12. Do you use teat dips? (yes or no)

13. Do you do dry therapy? (yes or no)

14. Do you cull affected animals? (yes or no)

15. Do you Mix milk from different cows? (Yes or no)

16. If yes do you milk mastitic cows differently? (yes or no)

17. If yes what do you do with the mastitic milk? _____

Appendix 2

Cow factors and California mastitis test results

Cow ID	Breed	Parity	Milk production per day in L	Stage of lactation (1–2) early (3–6) mid (>7) late	History of mastitis (yes/No)	CMT results for each quarter
Cow 1						FR HR FL HL
Cow 2						FR HR FL HL

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Glossary

Mastitis: Inflammation of the mammary gland, usually caused by bacterial infection.

Clinical mastitis: Mastitis with visible symptoms such as swelling, redness, heat, pain, and abnormal milk.

Subclinical mastitis: Mastitis without visible symptoms, but with detectable changes in milk composition (e.g., increased somatic cell count).

Somatic Cell Counts (SCC): The number of somatic cells (e.g., white blood cells, epithelial cells) in milk, indicating the degree of inflammation in the mammary gland.

Dry cow therapy: Treatment of cows' mammary glands with antibiotics during the dry period (between lactations) to prevent mastitis.

Strip cups: Devices used to examine milk for clots or flakes, indicating possible mastitis.

Purposive survey method: A research method where participants are selected based on specific criteria relevant to the research question.

California Mastitis Test (CMT): A simple on-farm test used to detect subclinical mastitis.

Semi-intensive management farming system: A livestock production system where animals have access to both pasture and confinement areas.

Intensive System: A livestock production system where animals are confined indoors with limited access to outdoor space.

Zero Grazing: A livestock production system where animals are fed entirely indoors and have no access to pasture.

Parities: The number of times a cow has given birth.

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