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RESEARCH ARTICLE

Inhalation risk assessment of airborne alcohol vapour among university laboratory workers

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Abstract - This study investigates the inhalation risks of occupational exposure to alcohol vapours among workers in university laboratories. The study focused on 3 types of alcohol which are ethanol, methanol, and isopropyl alcohol present in the university laboratories, and subsequently, the associated health risks. The research aims to assess exposure levels and potential health risks to inhaling alcohol vapour during routine laboratory activities such as disinfection and solvent preparation. The samples were collected from the breathing zones of the workers using the NIOSH 1400 method and were analysed using a gas chromatography-flame ionisation detector. Key factors influencing exposure, such as air velocity, relative humidity, and temperature were evaluated. Results showed that ethanol had the highest individual concentration at 2604.65 mm/m^3. This value has exceeded the permissible exposure limit of 1880 mg/m^3 according to USECCH Regulations 2000. The non-carcinogenic risk of ethanol also surpassed the reference value of 1 indicating that there are potential health risks due to the exposure to ethanol. Considering the high exposure concentrations and their associated non- carcinogenic risks, the use of personal protective equipment and the installation of ventilation systems are needed to reduce the exposure concentration of alcohol among the workers.

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1. Introduction

The use of chemical substances is integral to many areas of teaching and research, especially in universities. During teaching and learning, chemicals are often handled by students and lab staff directly involved in chemical research and management. One such chemical is alcohol, which is commonly used in university laboratories [1]. Hence, individual safety and health must always be prioritised, especially for students, researchers, technicians, and laboratory assistants who are frequently exposed to hazardous chemicals [2]. Methanol, ethylene glycol, and isopropanol are commonly known as poisonous alcohols. Therefore, due to their volatility, these alcohols become harmful to human health, especially to lab assistants who are always present in the laboratory handling the alcohol [3]. Moreover, chronic exposure to methanol causes headaches, nausea, stomach problems, giddiness, dizziness, insomnia, conjunctivitis, visual impairments, and blindness in humans [4]. Hence, it is important to consider the dangerous health impacts caused by the inhalation of alcohol among laboratory workers in their working environments.

The alcohol present in the air can become toxic and hazardous to workers exposed to it, as it is used for several purposes, such as disinfection and sterilisation, as a solvent, as a preservative, for chemical synthesis, and for cleaning laboratory equipment. In conjunction with that, alcohol exposure can also be influenced by several factors, such as job factors (magnitude of exposure and existing control measures) and indoor climatic factors (air velocity, relative humidity, and indoor temperature). When laboratory workers are exposed to high doses of alcohol vapour, they can experience nausea, vomiting, throat irritation, nasal and mucous membrane irritation, as well as breathing difficulties like coughing, which makes it harder for them to breathe [5]. In addition to that, even a minor exposure to alcohol or vaporised alcohol has similar and potentially continuous effects on the brain regions known to be associated with addiction development and maintenance [6]. Therefore, to determine the inhalation risk of alcohol, the concentration of alcohol in the worker's breathing zone is measured.

Ethyl alcohol (ethanol) is commonly used as a disinfectant and antiseptic in industrial laboratories. A sterile atmosphere is maintained due to its efficacy against a wide range of bacteria and viruses. To avoid contamination, ethanol is frequently used to clean lab workstations and tools and to disinfect the workers' hands. Due to ethanol's high evaporation rate, surfaces dry more quickly, reducing the likelihood of contaminant development [7]. For example, aqueous alcohol solutions are effective against lipid-containing viruses, fungi, and bacteria but not against spores. They have varying effectiveness on non-lipid viruses and work best at around 70% concentration. Their key advantage is that they do not leave any stains on the treated surfaces [8]. Ethyl alcohol (ethanol) is a durable and versatile solvent utilised for a variety of processes in industrial labs. It is beneficial when other solvents are ineffective, as it can dissolve both polar and nonpolar substances. Therefore, it is a preferred option in labs that prioritise safety because it is less hazardous than other solvents such as methanol and dichloromethane [7].

A study conducted by Ernstgard found that women inhaled less 2-propanol than men but exhaled more, especially after 10 minutes of exposure [9]. Bianchi et al. [10] found that ethanol vapour exposure reduced heart rate in both male and female rats, with females showing a greater effect. Acetaldehyde, a byproduct of ethanol, was shown to induce cardiac

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problems in females by Duan et al. [11]. Additionally, Bianchi et al. (2019) discovered that females exposed to ethanol exhibited elevated parasympathetic cardiac activity, which may account for the decrease in heart rate.

In this study, job factors, such as exposure magnitude and existing control measures (ventilation systems and PPE), are observed to determine their influence on the inhalation concentration of alcohol vapour. A study conducted by Nazaroff & Weschler found that ethanol and methanol are among the more prevalent organic species in indoor air. Both methanol and ethanol possess several significant physiological and toxicological characteristics because excessive exposure to any of them might be detrimental to human health [12]. Acute exposure to ethanol vapour can cause symptoms such as headaches and numbness. These symptoms typically develop after 30 minutes of exposure to a concentration of 2620 mg/m^3 for a healthy individual. A report on worker exposure to ethanol found that an abrupt shift in ethanol concentrations from 0 to 3600 mg/m^3 can induce temporary discomfort. Higher concentrations of ethanol at 9500 mg/m^3 can cause acute irritation of the eyes and upper respiratory tract (cough) for a brief period of 5 to 10 minutes [13]. As for the ventilation systems, they are designed to remove and dilute contaminants from the air while still supplying clean air for occupants to breathe. The emission rates and indoor concentrations of organic molecules such as methanol and ethanol can also be impacted by changes in the ventilation system. When mechanical ventilation was operating, and the air exchange rate was 0.4 h^{-1}, the methanol emission rate in a "net-zero-energy" home was 14±2 mg/h. The emission rate dropped to 8.6 ± 1.1 mg/h when ventilation was turned off, and the air exchange rate fell to 0.05 h^{-1}. Although the PTR-MS did not detect ethanol and formic acid, their total emission rates were 16 ± 2 mg/h at a ventilation rate of 0.4 h^{-1} and 4.2 ± 2.0 mg/h at ~0.05 h^{-1}, respectively.

According to these results, methanol and ethanol emissions increase with higher ventilation rates (and lower indoor concentrations), consistent with a similar conclusion about formaldehyde emissions by Hult et al [12]. Next, the indoor climatic factors, which are air velocity, relative humidity, and temperature, are studied to observe their effects on the inhalation concentration of alcohol vapour. Air velocity affects inhalation of alcohol vapours, as higher airflow can reduce the concentrations of ethanol and methanol in indoor air by dispersing these substances more evenly. Hence, this can reduce the workers' exposure to these compounds. Additionally, cleaner air entering the space can dilute indoor pollutants, including alcohol vapours, and prevent their accumulation from sources such as building materials and occupant emissions [12]. Relative humidity refers to the amount of moisture in the air, and indoor temperature affects the emission of alcohol vapours. Both methanol and ethanol have higher emission rates at warmer temperatures, which can increase their concentration in indoor air. For example, the methanol emission rate doubles when the temperature rises from 16°C to 23°C [12][14]. Ethanol concentrations can also be affected by temperature: cooler air can reduce ethanol levels in exhaled air due to slower evaporation rates, while hot, dry air can decrease ethanol concentration by accelerating evaporation during inhalation [15].

For the health risk assessment, inhalation exposure (Einh), chronic daily intake (CDI), and hazard quotient (HQ) are calculated to determine the inhalation risk posed by alcohol vapour in university laboratories. Inhalation as the route of exposure is the focus of this investigation. The inhalation dose-response is evaluated by considering the exposure period. Previous studies have examined alcohol exposure, especially from hand sanitisers used in laboratory settings. For example, Kramer et al. tested three different ethanol hand rubs (95%, 85%, and 55% ethanol) and found slight increases in blood alcohol levels after exposure to alcohol vapour, though the levels were low [16]. Another study by Brugnone et al. found detectable levels of isopropyl alcohol (IPA) in workers' alveolar air but not in their blood or urine [17]. Additionally, Dumas Campagna et al. studied ethanol exposure in an inhalation chamber and found that after 4 hours of exposure, blood alcohol levels peaked at 0.3mg/dL in men and 0.27 mg/dL in women, depending on the ethanol concentration [18]. Hence, inhalation exposure indicates the amount of alcohol vapour inhaled by workers. The hazard quotient (HQ) was computed to evaluate any potential risks posed by the non-carcinogenic effects of the alcohol vapours released [19]. The maximum quantity of pollutants that can be consumed by humans per unit weight per unit time without causing adverse effects is indicated by the HQ value [20]. A reference value of less than or equal to unity (HQ ≤ 1) was considered the tolerable risk for non-carcinogens.

2. Materials and Methods

This study is categorised as a quantitative cross-sectional research design. For this study, samples of alcohol vapour are collected from workers in 2 different laboratories within the FIST Laboratory at Universiti Malaysia Pahang Al-Sultan Abdullah. A personal air-sampling pump and charcoal tubes were used to measure the concentrations of alcohol vapour inhaled by the workers from their respiratory zones. The samples collected with the personal sampling pump were analysed by gas chromatography with a flame ionisation detector (GC-FID) to determine the concentrations of alcohol vapour in the air inhaled by the workers. Then, an inhalation risk assessment was conducted to assess the health risks posed by inhaling alcohol vapour to the workers. The data collection step was conducted as shown in Figure 1. The samples were taken from 2 different laboratories from the Faculty of Industrial Sciences and Technology. This study focused on workers in the analytical chemistry and microbiology laboratories, as only those working here handle alcohol-containing substances, thereby exposing them to alcohol vapour. Due to insufficient time and a small number of participants, only 2 samples were collected from the workers' respiratory zones. Air from the workers' respiratory zone was collected for 4 hours during the work shift. The sampling method used in this research is NIOSH Manual of Analytical Methods (NMAM) Method 1400. The NMAM method 1400 is used to measure aliphatic hydrocarbons via a personal sampling pump by using a charcoal tube and gas chromatography–flame ionisation detector (GC-FID). For the sample preparation, a solid sorbent tube with 150 mg of coconut shell charcoal is opened at both ends and placed in a holder. The flow rate of the air sampling pump is maintained at 0.2 L/min ± 5% to ensure optimal airflow. The mass of alcohol present

in the sample front (Wf) and back (Wb) sorbent sections, as well as the average media blank front (Bf) and back (Bb) sorbent sections, were calculated. The personal sampling of alcohol vapours was conducted for 4 hours at the selected laboratories. As for the data on indoor climatic factors (air velocity, relative humidity, temperature), they were collected using the Indoor Air Quality (IAQ) meter. Next, for the data analysis, the sociodemographic characteristics, risk factors, mass concentration of alcohol in the charcoal tube, individual concentration of alcohol, indoor climatic factors, adjusted air exposure concentration, chronic daily intake (CDI), and non-carcinogenic risk were measured.

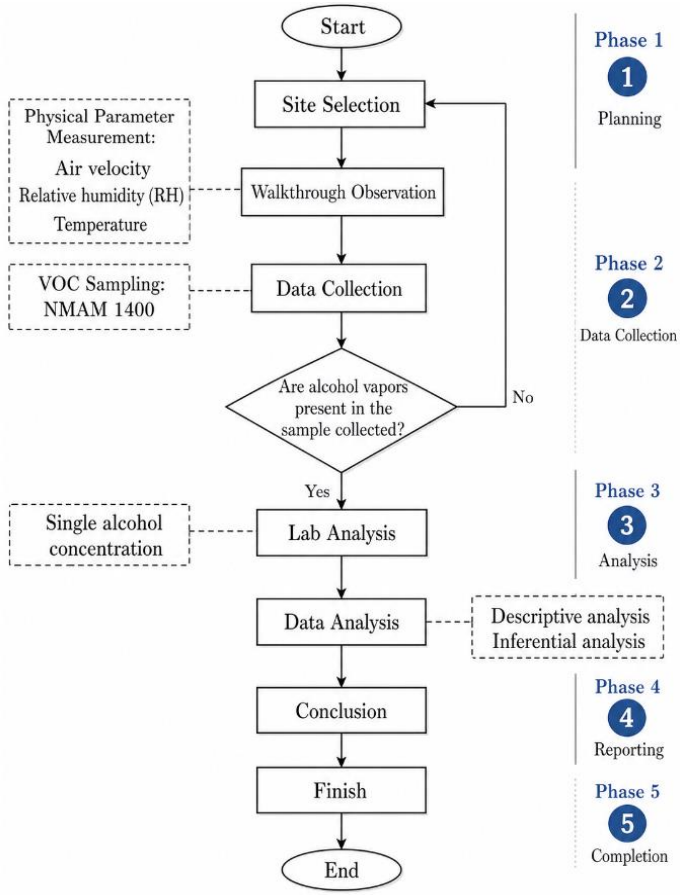

Figure 1. Methodology flowchart

3. Results and Discussion

3.1 Mass Concentration of Alcohol Vapour

Table 1 shows the alcohol mass concentration recorded in the breathing zone of both respondents. The highest concentration of alcohol vapour was recorded at respondent 1's analytical chemistry lab, at -5757.58 mg/m^3, followed by -42131.15 mg/m3 at sampling point 2, from respondent 2, who was at the microbiology lab. This is because the volume of air sampled differs between the two respondents. Due to time constraints, the sample from respondent 1 was collected over 163 minutes, while the sample from respondent 2 was collected over 303 minutes. Apart from that, there was also a breakthrough in the sample, and sample loss has occurred, as the weight of the sample back is not less than 10 times the weight of the sample front. Hence, the collected sample is inadequate to determine whether workers are exposed to alcohol vapour. In addition to these factors, indoor climatic conditions also contribute to the concentration of alcohol vapour at each sampling point. The air velocity recorded at sampling point 2 is much higher than that at sampling point 1. Hence, the alcohol vapour in sampling point 2 dispersed easily, and the reading of the alcohol vapour recorded at sampling point 2 was lower than at sampling point 1. This might also be due to the opening and closing of the doors at sampling point 2, which might have disrupted the air velocity inside the sampling point. Furthermore, the relative humidity at sampling point 2 is much lower than at sampling point 1, resulting in a lower recorded alcohol vapour concentration at sampling point 2. Although there was a lower moisture content at sampling point 2, the high temperature and air velocity at sampling point 2 caused the concentration of the alcohol vapour to be low.

Table 1. Mass concentration of alcohol vapour

Respondent	W*f* (mg)	W*b* (mg)	B*f* (mg)	B*b* (mg)	Volume of air, V (m^3)	Concentration (mg/m^3)
1	121.5	25.2	121.4	27.2	0.33	-5757.58
2	68	39.5	77.9	55.3	0.61	-42131.15

3.2 Individual Concentration of Alcohol

Table 2 shows the individual concentrations of the alcohol vapour collected from the breathing zones of both respondents. It can be concluded that laboratory workers are highly exposed to ethanol. According to the Occupational Safety and Health Regulations 2000, the permissible exposure limit (PEL) for ethanol is 1880 mg $m^{-3,}$ equivalent to 1000 ppm. However, respondent 1's exposure at the analytical chemistry laboratory exceeds this limit by 38.55%. Hence, this exposure might be dangerous to the worker, as it could cause eye, nose, and throat irritation due to the high concentration of ethanol. Respondent 2's ethanol exposure is below the PEL of 634.95 mg $m^{-3,}$ which is a safer concentration. The PEL for methanol is 262 mg m^{-3} (200 ppm), and for isopropyl alcohol, it is 983 mg m^{-3} (400 ppm). Therefore, the workers' exposure concentrations of methanol and isopropyl alcohol did not exceed the PEL, as they were negative. Although the concentration of ethanol inhaled by respondent 2 did not exceed the PEL, it is vital to consider wearing PPE to ensure that the workers there do not experience any long-term health effects from inhaling ethanol vapour. The high ethanol concentration might be due to the high ethanol content of the disinfectant used by laboratory workers. For example, according to the questionnaire completed by respondent 1, they use ethanol as a disinfectant for workstations. Therefore, a large amount of ethanol-containing disinfectant might have been used over a long period. Moreover, the ethanol concentration (%) in the disinfectant also influences the alcohol vapour concentration inhaled by the workers, as a more concentrated disinfectant with a higher ethanol content causes them to inhale more highly concentrated alcohol vapour. In addition, during the walkthrough observation, it was noted that two adjacent laboratories are connected by a small office, which could allow the dispersion of contaminants from one lab to another. Therefore, the inhaled air of the workers contains a high concentration of ethanol vapour, as well as methanol and isopropanol.

Table 2. Individual concentration of alcohol

Pollutant	Sample 1 (Analytical Chemistry Lab)	Sample 2 (Microbiology Lab)
	Concentration (mg m^{-3})	
Methanol	-4849.43	-319.26
Ethanol	2604.65	634.94
Isopropyl Alcohol	-23698.14	-1941.63

3.3 Adjusted Air Exposure Concentration

Table 3 presents the adjusted air exposure concentration by exposure duration, used to assess inhalation exposure to alcohol vapour. The purpose of calculating the adjusted air exposure concentration is to measure the duration, frequency and time of exposure. This adjustment allows for a comparison between inhalation cancer risks and duration-related non-cancer health indicators. However, actual exposures to indoor air depend on several variables, including ambient air concentrations of alcohol vapour, the rate of air exchange between the building and the surrounding environment, and the rate of contaminant emission from indoor sources [21]. From Table 3, ethanol has the highest exposure concentration (11720.93 mg m^{-3} and 2857.23 mg m^{-3}) for both respondents. The second-highest exposure concentration was recorded for methanol at -1436.67 mg m-3, followed by isopropyl alcohol at -8737.335 mg m^{-3} from respondent 2. This is because ethanol (ethyl alcohol) and isopropyl alcohol (isopropanol) are commonly used as disinfectants in laboratories, hence the high exposure to alcohol vapour among workers. Several recommendations and recent studies have addressed the disinfectant properties and applications of ethyl or isopropyl alcohol when used as aqueous solutions without additional components. Their rapid onset of action, broad-spectrum antibacterial activity, ease of application, non-staining nature, and tolerable odour are among their advantages [22]. In their assessment of the use of alcohols as antiseptics and disinfectants, Ali et al. cited several early studies and noted that 70% isopropyl alcohol has been used as a surface spray in certain food-handling scenarios. According to this study, 70% alcohol solutions are a good option for intermediate-level disinfection of noncritical and some semi-critical instruments that can be submerged for 10 minutes. In addition, this study revealed that several earlier studies used 50% or 70% ethyl alcohol to disinfect small instruments such as thermometers. Moreover, methanol is used as a disinfectant and as a solvent for making laboratory standards. Hence, this indicates that a high alcohol concentration in the disinfectant spray or liquid can cause workers to inhale high levels of alcohol vapour, as shown in Table 3.

Table 3. Adjusted air exposure concentration

Pollutant	Sample 1 (Analytical Chemistry Lab)	Sample 2 (Microbiology Lab)
Exposure Concentration (mg m^{-3})		
Methanol	-21822.435	-1436.67
Ethanol	11720.93	2857.23
Isopropyl Alcohol	-106641.63	-8737.335

3.4 Chronic Daily Intake

Table 4 shows the Chronic Daily Intake (CDI) of the alcohol vapour by both respondents. There are several methods to determine exposure levels, but the chronic daily intake is one of the most significant and frequently applied in risk assessment. This measure was added as exposure concentration (EC) in the 2009 EPA risk assessment guide for inhalation exposures. The amount of exposure to the chemical substance and the number of hours, days, and years of exposure are

among the variables that affect the exposure concentration [23]. It can be inferred that ethanol has the highest chronic daily intake for both workers: 461.51 × 10^3 mg kg−1 day−1 at sampling point 1 and 166.67 × 10^3 mg kg−1 day−1 at sampling point 2. Both concentrations indicate that ethanol might cause adverse health effects to the workers. Long-term exposure to ethanol might cause instant eye and upper respiratory tract discomfort, such as cough [13]. In addition to that, frequent inhalation of ethanol vapours is prone to cause headaches, eye and upper respiratory tract irritation, drowsiness, and decreased concentration. However, the risk of serious acute poisoning from ethanol vapour inhalation is minimal because ethanol's analgesic effects only occur at high concentrations, which would cause intolerable irritation.

Table 4. Chronic daily intake

Pollutant	Sample 1 (Analytical Chemistry Lab)	Sample 2 (Microbiology Lab)
Chronic Daily Intake (mg kg^{-1} day^{-1})		
Methanol	-859.26 x 10^3	-83 x 10^3
Ethanol	461.51 x 10^3	166.67 x 10^3
Isopropyl Alcohol	-4.20 x 10^6	-509.68 x 10^3

3.5 Non-Carcinogenic Risk

The non-carcinogenic risk of the inhaled alcohol vapour is assessed for the three species of alcohol. Hence, to determine this, the hazard quotient and hazard index were calculated to assess the effects of each alcohol on laboratory workers. Table 5 shows the non-carcinogenic risk of inhaled alcohol vapours for workers. An HQ < 1 indicates a low probability of adverse health effects, whereas an HQ > 1 suggests that exposure may pose risks to sensitive individuals [19]. According to Table 5, the non-cancer risk values for ethanol for both respondents exceeded the safe level of 1. This shows that ethanol vapour might cause significant health problems for both workers but does not greatly affect them. The non-cancer risk for ethanol was the highest at the analytical chemistry laboratory at 6.23. On the other hand, the non-cancer risk values for methanol and isopropyl alcohol at both laboratories showed tolerable non-carcinogenic risks with HQ < 1. Nevertheless, exposure to various hazardous contaminants could lead to synergistic effects or sequential interactions [19]. The hazard index was also calculated to describe the non- carcinogenic risk of alcohol vapour. The HI value is the highest for respondent 2 at -12.85. Therefore, the HQ and HI values show that there are no non-carcinogenic risks present except for ethanol.

Table 5. Non-carcinogenic risk

Pollutant	Sample 1 (Analytical Chemistry Lab)	Sample 2 (Microbiology Lab)
	Hazard Quotient (HQ)	
Methanol	-83.29	-5.48
Ethanol	6.23	1.52
Isopropyl Alcohol	-108.49	-8.89
Parameter	Sample 1 (Analytical Chemistry Lab)	Sample 2 (Microbiology Lab)
HI (**Σ HQ**)	-185.55	-12.85

4. Conclusions

Adherence to safety measures and the use of personal protective equipment are crucial to minimising employees' exposure to alcohol vapour. One effective method is to wear respirator masks, which filter out alcohol vapours near workers' breathing zones. A study by Schütz et al. demonstrated that disposable respirator masks provided significant protection from ethanol and isopropanol vapour, even after prolonged exposure (4 hours). Another crucial factor in improving worker safety is installing a proper ventilation system. The Industrial code of practice on IAQ 2010 emphasises that healthy indoor air quality is vital for preventing immediate and long-term health issues, such as allergies, respiratory problems, and sinusitis. However, this study has some limitations, as only two samples were collected to measure alcohol vapour concentration, which may not provide sufficient data to accurately assess exposure levels. Additionally, the exposure lasted less than 4 hours, which is shorter than the standard 8-hour time-weighted average used in occupational health risk assessments. This short duration might affect the accuracy of the results. The study also focused on three types of alcohols, namely ethanol, methanol, and isopropyl alcohol, while other alcohol vapours like butanol and propanol could be present and should be considered in future research for more comprehensive data. In this study, alcohol vapour concentrations were measured in the breathing zones of workers in university laboratories. Ethanol was the most abundant alcohol found, with the highest recorded concentration of 2604.65 mg/m^3 in the analytical chemistry lab. Several factors influenced the alcohol vapour concentration, including indoor climatic conditions (air velocity, relative humidity, and temperature) and ventilation. The amount of suspended alcohol vapour in the air was influenced by relative humidity, whereas the dispersion of alcohol vapour was regulated by air velocity. Non-carcinogenic risks were observed for ethanol exposure in both laboratories. Given the high concentrations of alcohol vapours and the associated health risks, using respirators and installing effective ventilation systems in laboratories is crucial. The use of alcohol-based disinfectants and solvents with lower alcohol concentrations is also recommended to prevent health issues for workers.

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Declaration of Competing Interest
The author declares no conflicts of interest.

CRediT Authorship Contribution Statement
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Availability of Data and Materials
The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations
This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations
The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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