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Research article

Lessons learnt from horse-related human fatalities: Accident analysis using HFACS-Equestrianism

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A R T I C L E I N F O

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A B S T R A C T

Equestrianism has an opportunity to learn lessons relating to safer human-horse interactions from those who no longer have a voice, by drawing data from the investigation of horse-related human fatalities and participating in accident analysis. Many human-horse related injuries and fatalities are not examined in equestrianism for the purpose of developing safer future risk mitigation practice, often due to the philosophy that horse sport is simply dangerous.

This study analysed data from the Australian National Coronial Information System (NCIS) relating to fatalities involving human-horse interaction that occurred between 2000 and 2020. A total of 50 human-horse related fatalities were identified from the NCIS database for analysis using a validated accident analysis framework. The aim of the study was to identify what we could learn and potentially do differently to prevent future fatalities. This was done through a detailed frequency analysis of the underlying causes identified from the coronial investigation using Human Factors Analysis and Classification System-Equestrianism (HFACS-Eq), an accident analysis model specifically designed for equestrianism. As to be expected, the analysis found that most fatalities involved falls 56 % (n = 28) resulting in blunt force trauma 96 % (n = 48), with the horse as causal factor 90 % (n = 45).

Beyond these obvious findings, the HFACS-Eq analysis revealed additional findings that in turn can guide future health, safety, and welfare advances in equestrianism. The analysis presented in this paper highlights the environment, surroundings, or location in which the human-horse interact as a critical factor of accident causation. Also, the role of non-technical skills such as communication, effective supervision, and adequate leadership were highlighted as factors that could contribute to enhanced safety in this high-risk domain. The human-horse dyad in equestrianism is complex and unique when compared to other high-risk work and non-work activities. A better understanding of the risk factors involved in handling and riding horses, coupled with a model to help mitigate that risk will also set us on the path to a good life for horses because human safety and horse welfare are inextricably linked.

1. Introduction

For many years, researchers have sought to understand and learn more about the human-horse dyad and the interspecies

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relationships during work, sporting activities, and when humans engage horses as companion animals, or work with them as participants during equine-assisted human therapy [1]. Equestrianism, can be defined as the association of equids and humans during work, leisure, and sport activities, and today it is a multi-billion-dollar global industry [2–5].

The complexity of human-horse interactions in equestrianism involves direct physical contact of these two very different species, which requires a high level of risk mitigation [6,7]. Humans are particularly vulnerable to injury, being smaller in size and weight when compared to horses, and thus susceptible to serious injury or death following a dangerous interaction with a horse [8,9].

Every day, humans die or are seriously injured worldwide in both work and non-work environments due to horse-related interactions [10,11]. Horses are known to be dangerous, and the environment in which humans and horses interact can potentially contribute to human injuries, or fatalities [12–16]. The cost of sport-related injuries in Australia has been estimated at $1.8 billion per annum. Even more devastating are the long-term effects that a serious injury or the loss of a loved one's life have on families and their wider communities [17,18]. Therefore, accident investigation and analysis, leading to the identification of areas for safety improvements, has the potential for far-reaching benefits for high-risk industries such as equestrianism.

High-risk workplaces routinely conduct investigations following incidents, with more complex reviews occurring after a fatality. These investigations are often required by an industry regulator, or undertaken by an independent body [19,20]. The purpose of these investigations is to learn what went wrong, prevent a reoccurrence, and make changes to the Workplace Health and Safety Management System (WHSMS) to improve safety standards and mitigate future risk [20–25].

To support incident investigation, there are numerous accident analysis frameworks available to industry, many of which are very complex, require user training and are relevant to a specific industry type [26]. Further, many of these accident frameworks are unable to include the potential accident causation factors of the human-horse dyad in which these interactions occur. Human Factors Analysis and Classification System (HFACS) is an accident analysis framework that can be adapted for various industry types, accommodating specific industry categories, including equestrianism [27,28]. Whereas other popular accident causation models such as Rasmussen's (1997) Accimap and Leveson's (2004) Systems-Theoretic Accident Model and Process (STAMP) are less adaptable to reflect equestrianism activities [29]. Human Factors (HF) analysis used by many high-risk workplaces, is the science of understanding human capabilities and applying this knowledge to develop safer work processes, equipment design, and WHSMS. This broad framework also considers human error contributions during accident analysis. The concept of human error originated in the United States Air Force to investigate and analyse HF contributions during aviation accidents [30]. Human error can be described as either a) an unintentional human action or decision; or b) violations being intentional wrongful acts. The way humans respond to hazards and the risks they pose to human safety, others, and the environment is important. Human *slips and lapses,* being skills-based errors or mistakes, all contribute to reducing efficient, effective, and safe work or non-work activities and environments [31].

Recently, a new accident analysis framework for equestrianism has been developed, namely Human Factors Analysis and Classification System - Equestrianism (HFACS-Eq). This framework captures accident contributions from the triad of human, horse, and environmental factors. HFACS-Eq included the horse as a hazard category and equestrianism language with examples to support the users understanding and classification of potential accident causal factors [32]. Using accident analysis to identify how we can do better in equestrianism is one of the keys that may open the door of change and help reduce human-horse related injuries and fatalities.

Human-horse related interactions are by their very nature high-risk regardless of where the interactions take place, be that work or non-work environments [33–37]. Equestrianism lacks an integrated approach to WHSMS and accident analysis, with formal systems starting to be applied in a few workplaces such as racing and breeding farms, the mounted constabulary and agricultural industries where horses work-with humans during mustering activities and some sporting associations [38,39]. Accordingly, incident investigations are not routinely undertaken in many contexts, and therefore, reliable datasets for detailed analysis are lacking. Exceptions to this are the small subset of human-horse incidents that result in a fatality. In Australia, all unexpected deaths are subjected to some form of coronial investigation, and a national database is maintained with the findings and associated documentation relating to each investigation, known as the National Coronial Information System (NCIS) [40].

Typically, coroners have two tasks 1) to establish the cause of the death and 2) make recommendations to prevent a reoccurrence [41]. Critically examining available data from National Coronial repositories, and identifying the causal factors of fatal accidents may enable the identification of trends, and in turn appropriate targets for interventions to enhance safety in equestrianism [42,43]. To reduce human-horse related accidents, a better understanding of why these accidents continue to occur is required.

The NCIS is a secure repository where specific coronial findings, and associated reports such as police statements, forensic toxicology, and autopsy reports are stored. In addition, demographic information about the deceased person and contextual details on the nature of the fatality are also reported where available [44]. The primary purpose of the NCIS database is to provide information to coroners during investigations, with mechanisms in place for external access for research purposes, with appropriate ethics approvals.

Given the paucity of accident data analysis, the research presented in this paper applied a validated, equestrianism-specific accident analysis framework to examine records of coronial investigations into horse-related fatalities from the NCIS database. The aim of this study was to examine the causal factors that contributed to these fatal accidents, with a focus on identifying common causal factors that might in turn, identify targets for safety interventions.

2. Material and methods

2.1. Data set and inclusion and exclusion criteria

The NCIS database was searched for the fifty most recently completed coronial investigations of horse-related human fatalities, which were selected for HFACS-Eq analysis. Specific inclusion criteria included:

- Fatalities reported to an Australian Coroner between 2000 and 2020
- Cases from six Australian states and territories: New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA), Tasmania (TAS), Australian Capital Territory (ACT), excluding Western Australia (WA) due to local legal limitations.
- Fatalities in both work and non-work environments
- Cases that contained either the word horse, mule, donkey, or ass were included as an external cause
- All ages and genders

Specific exclusion criteria included:

- Cases that had not been *closed* by the coroner
- Cases that did not contain a police statement and/or report of coronial findings
- Cases where the death resulted from natural causes, was intentional or undetermined, resulted from legal interventions or if the body was not recovered.

Ethical approvals were granted prior to the commencement of this study from 1) Central Queensland University Ethics Committee (approval number H17/02–026, March 28, 2017) and 2) the Australian Justice Research Ethics Committee granting access to the NCIS database (approval number CF/17/1380, July 17, 2017).

2.2. Data sources

Data extracted from the data base for further statistical analysis were age, gender, work and non-work environments, Australian states, and territory locations. Other demographic information included occupation, specific location of fatality and cause of death. The mechanism of injury, being the force that caused the injury, for example, fall from a horse, a kick to the chest and the object type, which may be the horse, ground, or tree, for example, resulting in the 50 fatalities were also analysed. In addition, noting if a Workplace Health and Safety (WHS) investigation had been completed and/or a Coronial Inquest conducted along with any documented recommendations. Classification of associated documents with each coronial investigation, such as police statements, coronial findings, forensic toxicology, and autopsy reports, were sourced from the NCIS database where available. These documents provided descriptive details of the accident, pre-accident conditions and human factors, with reports provided the horse's history, education, and behaviours and were subjected to classification using the validated equestrianism specific accident analysis framework HFACS-Eq [32].

2.3. Classification

2.3.1. HFACS-Eq framework

The HFACS-Eq framework provided a validated and standardised equestrianism accident analysis process to complete classification of NCIS data [32]. HFACS-Eq provides a taxonomy of fatality accidents across four distinct levels. These being 1) unsafe work-related influences; 2) unsafe supervision; 3) preconditions for unsafe acts such as the horse, environment, personnel, and operational factors and 4) unsafe human acts. The four levels then extend to categories, with additional sub-categories called nano-codes. Prior to applying HFACS-Eq for this study the research group modified two categories related to supervisory skills, experience, capabilities, and effort into one category, leaving a total of 18 HFACS-Eq categories.

Finally, a total of 58 HFACS-Eq nano-codes provided further clarification for each of the category's specific failures. Each of the nano-codes were accompanied by detailed explanations, with examples to provide more precise coding of the NCIS fatality data, whereby improving findings of more distal accident human error causal factors. A list of all 58 HFACS-Eq nano-codes can be sourced from the recently published paper 'Development of a Human Factors Approach to Equine-related Human Accident Analysis, and Preliminarily Evaluation with Simulated Incidents' [32].

2.3.2. Data analyses

Data were analysed using SPSS V28. Cross tabulation analysis was completed using Pearson Chi-Square [45] to identify associations between key demographic and contextual variables and classifications of accident causation using the HFACS-Eq [32]. All tests used a value of $p < .05$ for significance.

3. Results

3.1. Influence of demographic variables

Of the coronial cases included in the study, there were marginally more fatalities involving males (56 %, n = 28), than females (44 %, n = 22). There was no observed effect of gender with respect to distribution of HFACS-Eq levels 1) unsafe work-related influences; 2) unsafe supervision; or 3) preconditions for unsafe acts such as the horse, environment, personnel, and operational factors. A total of 45.5 % (n = 10) of the fatalities that involved females were associated with HFACS-Eq level 4) human unsafe acts, compared to only 17.9 % (n = 5) of fatalities that involved males (X^2 $(1, N = 50) = 4.5, p = .035$). In addition, within this HFACS-Eq level, 22.7 % (n = 5) of the fatalities involving females were associated with *cautious adherence* compared to only 3.6 % (n = 1) of male fatalities X^2 $(1, N =$

50) = 4.3, $p = .039$. Relationships were observed between gender under the category *operational processes* with only fatalities involving females (13.6 %, n = 3) being associated with the causal factor nano-code of *insufficient guidance or procedures* (X^2 (1, $N = 50$) = 4.1, $p = .044$). Also, 27.3 % (n = 6) of fatalities involving females were associated with the causal factor sub-category of *corrections*, compared to 3.6 % (n = 1) of fatalities involving males X^2 (1, $N = 50$) = 5.7, $p = .017$. In addition, relationships were highlighted between gender and the category of *social environments* and specifically the nano-code a *competitive environment* where 18.2 % (n = 4) of female fatalities were associated with this causal factor compared to no male fatalities (X^2 (1, $N = 50$) = 5.5, $p = .019$).

Of the fatalities that involved females, 100 % (n = 22) were associated with the causal factor category *horse sentient-living being*, compared to 82.1 % (n = 23) of male fatalities (X^2 (1, $N = 50$) = 4.4, $p = .037$), which suggests non-horse-related causal factors were more prevalent in fatalities involving males. Finally, a relationship was highlighted between the category *horse sentient-living being* as a causal factor which was associated with 100 % (n = 27) of non-work related fatalities, compared to 78.3 % (n = 18) of work related fatalities X^2 (1, $N = 50$) = 6.5, $p = .011$). This suggests the *horse sentient-living being* is a causal factor associated with most human fatalities during human-horse interaction resulting in human death.

Of the 50 fatalities, 56 % (n = 28) resulted from a fall of a height of greater than 1 m, most likely indicative of riding rather than handling horses, whereas 24 % (n = 12) resulted from direct horse contact and 6 % (n = 3) crushed by a horse, with 14 % (n = 7) not recorded. Falls resulting from contact with or being crushed by a horse, were consistent with other research [46]. The youngest human fatality was reported to be an eight-year-old female and the oldest a male of 85 years. (See Fig. 1).

In general, only slightly more fatalities occurred in a non-work environment (54 %, n = 27), compared to 46 % (n = 23) reported as occurring in a voluntary or paid work environment. The humans' occupation and location of each fatality for the purpose of data analysis were grouped according to NCIS inclusions, with a definition provided for further explanation as necessary. The primary location where most of the human-horse related fatalities occurred were on farms (34 %, n = 17), followed by sporting and education facilities (28 %, n = 14). (See Table 1).

The most common mechanism of injury identified was blunt force trauma to the body which caused 96 % (n = 48) of the NCIS fatalities, the other 4 % (n = 2) were due to respiratory complications. Blunt force human trauma injuries may include bruising, abrasions, lacerations, or internal haemorrhages which typically result from impact. An impact event can occur from contact, a force or blow with a dull, firm surface such as the ground, even an object such as a horse or fence. The most significant causes of human trauma in this study are outlined in the graph below (See Fig. 2).

With respect to the geographic distribution of horse-related human fatalities in Australia, numbers closely tracked the population of each state, with a higher number of fatalities recorded in New South Wales (NSW), Victoria (VIC), and Queensland (QLD) (See Table 2).

This study analysed data from the Australian NCIS relating to fatalities involving human-horse interaction that occurred between 2000 and 2020. To understand the distribution of underlying causes of horse-related human fatalities, frequency analysis was completed for each category within the four HFACS-Eq framework levels for all 50 fatalities.

3.2. Unsafe work-related influences

The HFACS-Eq level of unsafe work-related influences was a causal factor in 8 % (n = 4) of all fatalities. Operational processes with insufficiencies in *monitoring and task activity review* and *guidance or procedures* both contributed to 6 % (n = 3) of all causal factors. Communications 4 % (n = 2) and o*perational pace and or workload* 2 % (n = 1) that was insufficient, or poor was a causal factor. In addition, an *insufficient manager or management team* 2 % (n = 1) associated with an *organisation or sole trader* was highlighted as a casual factor. In general, organisational culture was not a contributor to fatalities in this study.

3.3. Unsafe supervision

Unsafe supervision contributed to 24 % (n = 12) of causal factors for all fatalities including the inability of humans to identify *corrections* 14 % (n = 7), with *high-risk behaviour* 10 % (n = 5), *equipment deficiencies* 4 % (n = 2) and horse unsuitability 2 % (n = 1) not being corrected. In addition, overall supervisory skills 8 % (n = 4), with insufficiencies in *supervision experience for an individual or team* 4 % (n = 2), *communication or coordination* 2 % (n = 1) and *inattentive supervision to follow or enforce existing routines or rules* 4 % (n = 2) were all causal factors. Supervision includes the task of *planned appropriate actions* with 8 % (n = 4) contributing to casual factors of all fatalities, these being insufficient risk management (hazard identification, risk assessment pre task or activity of 6 % (n = 3) and horse behaviour or temperament assessment contributing to 2 % (n = 1) of all fatalities.

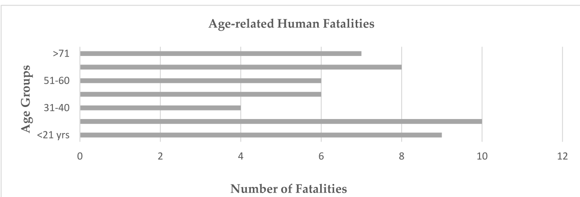

Fig. 1. Number of human fatalities within age-related cohort groups.

Table 1
NCIS non-work, work and locations of all 50 fatalities.

NCIS Classifications	NCIS Definitions	Frequency N =	% all fatalities
Non-Work 54 % (n = 27)	Retirees/pensioners, students, Au pair, home duties and volunteers	14	28 %
	Unknown	13	26 %
Work 46 % (n = 23)	Professional Workers and self-employed persons	9	18 %
	farmer/overseer and jockeys	7	14 %
	horse trainers	5	10 %
	track work riders	2	4 %
Locations	Farms	17	34 %
	Sport or athletic facilities including racetracks or courses, equestrian or sporting grounds, schools, universities, and adult education areas	14	28 %
	Roadways, including public roads and highways, streets, dirt roads and bush tracks	11	22 %
	Countryside including bushlands, forest, national parks, beach, body, or stream of water	4	8 %
	Home	3	6 %
	Unknown	1	2 %

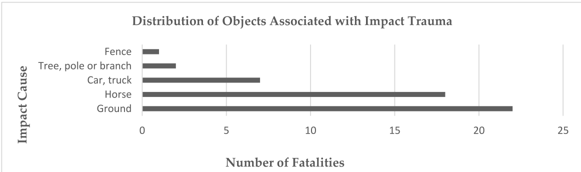

Fig. 2. Distribution of objects associated with human body trauma following contact, a force or blow associated with a dull or firm surface.

Table 2
Distribution of fatalities by Australian States or Territories (excluding Western Australia).

Australian States	NSW	VIC	QLD	NT	SA	TAS	ACT
No of Fatalities	10	10	10	8	6	5	1
Percentage of total Fatalities	20 %	20 %	20 %	16 %	12 %	10 %	2 %

3.4. *Preconditions for unsafe acts*

Overall, the HFACS-Eq level preconditions for unsafe acts were a contributing factor in 44 % (n = 22) of all fatalities, with the horse as a *sentient and living being* resulting in the highest causal factor of 90 % (n = 45). Horses displaying *unfavourable responses, direct human impact or fall related outcomes* was a causal factor in 84 % (n = 42) of the human fatalities. Horses indicating *dangerous current or historical behaviours* were indicated as a causal factor in 26 % (n = 13), along with the horse having *insufficient capability or training required for the level of activity* and *suboptimal health*, both reported as 4 % (n = 2) causal factors.

The *physical environment or surrounds* in which both humans and horses interacted was identified as the next highest causal factor for 38 % (n = 19) of the fatalities. These being an *unfavourable or change in terrain* in 24 % (n = 12), *insufficient visibility* 8 % (n = 4), *insufficient or change to surrounding or design or layout for rider-handler-driver skill level* 6 % (n = 3), *unfavourable weather* 6 % (n = 3) and unfamiliar environment 4 % (n = 2) as causal factors. The third highest causal factor in this HFACS-Eq level, contributing to all fatalities was the human's physical health, where *known, recent or historical injuries or illness* were a causal factor for 20 % (n = 10) and 2 % (n = 1) having *insufficient food or sustenance and or fluids*. No gender specific differences were highlighted in this level. In addition, human physical, and cognitive deficits both contributed equally to 2 % (n = 1) overall causal factors.

Other causal factors were 16 % (n = 8) resources allocations, where *no helmets* were an identified causal factor in 12 % (n = 6) of all fatalities, *insufficient general equipment for the task or activity*, *equipment not correctly fitted* and *inappropriate horse-rider or handler match for the selected task or activity* each contributing 2 % (n = 1) for all fatalities.

3.5. *Human unsafe acts*

Results showed overall human unsafe acts were a contributing factor in 30 % (n = 15) of all fatalities. Human risk perception where humans *did not identify a hazard or problem* was a causal factor in 16 % (n = 8) of all fatalities, with cautious adherence being 12 % (n = 6), especially *not following careful or cautious behaviour* 10 % (n = 5) contributing to fatalities. Other causal factors relating to *routine adherence*, such as the human did *not follow routine or other rules or procedures correctly* contributed to 4 % (n = 2) of overall fatalities (See Table 3).

4. Discussion

This research has examined and reported on how the HFACS-Eq framework can be used to gain more insight into other accident causal factors, beyond the suggestion that horses are dangerous and the primary cause of most accidents [10,11]. Causal factors were identified across all four levels of the HFACS-Eq framework, with *Preconditions for Unsafe Acts* being the most frequently identified category, followed by *Human Unsafe Acts*.

4.1. Unsafe work-related influences

Less than one in ten coronial reports identified that Unsafe Work-related Influences contributed to the fatality. Whilst this finding may seem to suggest work-related factors played little role in accident causation, it is most likely a reflection of the approach to investigation undertaken into each horse-related fatality. For most of the fatalities in the dataset, coronial findings relied heavily on initial police reports, which in turn demonstrated a focus on the primary mechanism of injury and the surface-features of the accident sequence.

The HFACS framework was initially developed in the context of high-risk industries, where incidents and accidents are subjected to rigorous investigation that includes an explicit focus on organizational policy, procedure, systems and even organizational culture [47,48]. This level of investigation is quite different from the investigation undertaken for the majority of horse-related fatalities, where the primary purpose is to simply establish the cause of death and rule out any criminal culpability. Therefore, the lack of contributory factors associated with Unsafe Work-related Influences is not a surprising finding.

4.2. Unsafe supervision

Unsafe supervision was identified as a causal factor in approximately one in four fatalities. This may indicate adequate supervision was provided or not considered necessary, prior to the human-horse interaction, due to a perceived or predetermined level of safe human-horse interaction capability. Otherwise, three of the four fatalities may have resulted from other more predominant casual factors not related to supervisory requirements. The most frequently identified category was *corrections*. This refers to a human's ability to identify and assess imminent or potential risk and actively application of risk mitigating controls. The findings highlighted some causal factors, such as supervisory inability to *correct high-risk human behaviour*. Some coronial data examples were, 'not enforcing helmet use when the rider was requested to do so' and 'allowing a human to ride with a current injury, whilst under the influence of drugs and alcohol.' Other failed *corrections* were 'unsupervised riders' inability to safely access a horse's stride when approaching an obstacle and a rider not turning a horse during acceleration following supervisory instruction'. Whilst the HFACS-Eq framework provides equestrianism with a validated, consistent human horse-related accident analysis tool, deeper investigation into the underlying causes of human error are necessary [31,49]. Further analysis would identify not only the immediate actions of supervisors that led to *correction* errors but systemic issues, such as 'regular rule updates', which may have contributed to the supervisory oversight.

4.3. Preconditions for unsafe acts

It is not alarming that the *horse sentient-living being*, was the most frequent causal factor category, with just over half of the fatalities

Table 3
All HFACS-Eq casual factor frequencies and categories, reported as percentages of 50 incidents.

	HFACS-Eq frequency and percentage for each level and categories for all 50 incidents				
HFACS-Eq Levels	Frequency N =	% all incidents	Categories	Frequency N =	% all incidents
1. Unsafe Work-related Influences	4	8 %	Management Organisation/Sole Trader	1	2 %
			Culture	0	Nil
			Operational Process	4	8 %
2. Unsafe Supervision	12	24 %	Supervisory Skills	4	8 %
			Planned Appropriate Actions	4	8 %
			Corrections	7	14 %
3. Preconditions for Unsafe Acts	22	44 %	Physical Environment/Surrounds	19	38 %
			Social Environment	4	8 %
			Horse Sentient/Living Being	45	90 %
			Resource Allocations	8	16 %
			Personal Readiness	2	4 %
			Mental Health	0	Nil
			Physical Health	10	20 %
			Human Performance	2	4 %
4. Human Unsafe Acts	15	30 %	Skill-based Actions	0	Nil
			Perceptions	8	16 %
			Routine Adherence	2	4 %
			Cautious Adherence	6	12 %

resulting from a *fall from* a horse and nearly one in three fatalities occurring from direct human *harmful-horse contact.* These findings are consistent with other equestrianism research [8,50–53]. The most frequent causal factor nano-code was the horse displaying *unfavourable horse responses,* such as bolting, rearing, bucking, kicking, and shying. Some of these dangerous current or historical horse behaviours were reported as being known to the human prior to the fatality, with no changes to riding or handling practices evident. The popular 'Five Domains Model Framework' of animal welfare, highlights an intrinsic association of human injury risk to horse welfare management [49,54–56].

Research suggests humans who fall from a height greater than 1 m are more likely to sustain a life-threatening injury or degree of human trauma on ground or object impact [57,58]. Some *high-risk* industries like construction, enforce effective safety controls, such as Personal Protective Equipment (PPE) and fixed anchor points during work at heights [59–61]. However, not all *high-risk* industry safety controls are practical for equestrianism. For example, anchoring a rider to the horse is more likely to increase risk of human injury, because of the rider's inability to disengage from the horse and assume a safety *tuck and roll* for landing during imminent danger [62].

This research outlines what horses *need* as domesticated animals and *why* horses may respond differently. Equitation science enlightens us that if a horses primary needs of adequate nutrition, physical environment, health, behavioral interactions and overall mental state are met and integrate with human and environmental exposures, they are less likely to react with dangerous behaviours and compromise human safety [63–65].

Whilst research suggests human-horse interactions are *high-risk* activities, there appears to be a degree of *danger-acceptance* in equestrianism. Statements such as 'horses are just dangerous' are often accepted incident causation, particularly in the absence of eye-witness pre-incident accounts and thorough incident analysis [66]. More thorough incident causation analysis is likely to occur, with the *horse sentient-living being* included as a category within the HFACS-Eq framework. However, as previously identified incident outputs and findings rely upon available and informative police reports, eye-witness statements, and coronial findings.

The physical environment or surrounds where humans interact with horses was a causal factor in approximately one in three fatalities. This indicates the environment in which the human-horse *dyad* interacts, is equally as important in risk mitigation during human-horse interactions. The environment or surrounds is an *ever-changing* element that always requires careful human planning and monitoring when humans and horses interact. For example, adverse weather may cause a horse to shy or spook and alter the stability of the ground surface. Horse-related human injuries and fatalities are more likely to be reduced if those responsible for the health and safety of riders or handlers adopt an all-inclusive, *human-horse-environment triad* risk mitigation approach [12].

Approximately one in four fatalities were associated with ground surface instability, for example 'slippery surface', or 'changes in the terrain texture and visual variations'. In these coronial cases, horses reacted with 'unfavourable responses by shying, baulking, darting sideways and then bolting', resulting in a rider fall, which is not an unusual occurrence. However, these incidents reinforce the importance of humans being aware of how horses view, respond and interpret ground surface environmental hazards [67.].

Safer human-horse interactions are also dependent on optimal health and wellbeing of both species. Coronial data highlighted one in five fatalities were associated with causal factors of suboptimal human health and wellbeing, following 'recent recovery from illness, surgery, or a current physical incapacity'. Horse riding as a recreational sport meets the criteria for moderate intensity exercise [68]. Even ground human-horse interactions require the human to be agile and move quickly away from the horse if required. Based on these causal factor findings some incidents may have been prevented with less haste to return to riding or handling horses being a safer choice during suboptimal human health [69,70].

The coronial data also identified a helmet was not worn in approximately one in eight fatalities during human-horse interactions. This would indicate most were wearing a helmet as PPE. Over half of the fatalities were associated with a fall from greater than 1 m, indicating the fatalities occurred during riding activities and ground or stationary object impact. Also, just over one in four fatalities were associated with direct horse contact despite wearing a helmet. Research verifies helmets can reduce the severity of head trauma and concussions [71,72]. It is important to acknowledge other elements *value-add* to helmet wearing to reduce head impact trauma, such as correct fit, damage free, helmet style and kinematics [73,74]. With minimal decline in equestrianism human injury and fatality frequency rates, PPE should not be relied upon as the most effective risk control measure during human-horse interactions [8,66,75].

4.4. Human unsafe acts

Unsafe human acts were identified as a causal factor in approximately one in three fatalities. The most frequently identified category was *perception*. The implication of humans applying risk *perception* is 'having the ability to comprehend imminent hazards and rectify a problem' during human-horse interaction before an incident occurs [66,76–78]. Coronial data verified a few causal *perception* factors with some fatalities such as 'riding too close and clipping heels of the horse in front' and another 'entering a deep fast flowing river crossing on horseback'. Whilst these incident occurrences may be considered rational, risk *perception* may vary from one human to another, being shaped from prior experiences and even risk tolerance resulting in no prior harmful outcomes [66,79]. Understanding other variables that may influence human risk *perception* and safer judgements, like social interactions, economic perspectives, and psychological stimuli are likely to reduce future horse-related injuries and fatalities [80].

Finally, the HFACS-Eq framework highlighted a level of significance with fatalities involving females in level 4) *Human Unsafe Acts* and the category *cautious adherence* compared to male fatalities. Other categories like the *horse sentient-living being,* and *social environment* in level 3) *Preconditions for Unsafe Acts* and level 2) *Unsafe Supervision*, the category of *corrections* having similar significant findings. The findings of this research highlighted several important differences with respect to gender. Previous research indicates females who participate in the *high-risk* sport of equestrian are more likely to have the *perception* that human-horse interactions are less directly associated with a risk of injury or harm [66,81]. Whilst the category of risk *perception* was identified as the most frequent causal factor category associated with *Human Unsafe Acts*, gender differences did not reach a level of significance. Further research is necessary to identify other systemic factors that may influence safer human acts and behaviours, including gender differences during human-horse interactions.

5. Limitations

Coroners' findings provided some detail of the deceased's family, social, occupational history, and only occasionally their level of experience during human-horse-interactions. However, pre-accident information was limited due to a reliance on witness statements and police reports. Some coronial reports provided a summary of circumstances relating to each fatality, the mechanism of injury and cause of death which could be included in many HFACS-Eq nano-codes, whereas other reports were sparce on accident information. This resulted in inconsistent available accident analysis data reducing the ability of the validated HFACS-Eq framework to identify all potential accident causal factors. Also, information in police narratives was often limited and this may be due to the statements usually being obtained at the initial time of reporting the fatality. As such, police statements needed to be read as an initial description of the circumstances surrounding the accident. These details or recollections may vary upon further investigation and should always be analysed with this caveat. Unfortunately, consistent accident investigation records are not maintained at a national level in Australia for either work and non-work environments. This may be due to Australia having no designated governance or regulatory authority for equestrianism unlike other high-risk industries. Despite the inability to access consistent, complete, and informative human-horse related qualitative information/data, this study has yielded information that could be used to improve safety reporting and data collection practices and targeted risk mitigation strategies.

6. Conclusion

This study highlighted that many human horse-related injuries and fatalities can be prevented. By using the validated accident analysis framework HFACS-Eq we were able to systematically explore accident causal factors, including mechanisms of harm to identify areas of human failures that contributed to each of the 50 fatalities. Thus, if only one causal factor within the HFACS-Eq levels being 1) unsafe work-related influences; 2) unsafe supervision; 3) preconditions for unsafe acts (horse, environment, personnel, and operational factors) or 4) unsafe human acts were absent, one or more of these human horse-related fatalities may not have occurred. Equestrian work or non-work environments can only become safer for humans and horses with ongoing research focusing on accident causation, human factor analysis, equitation science and horse welfare. A proactive injury prevention approach in equestrianism would include 1) the implementation of modified high-risk workplace health, safety and welfare best-practice management system, 2) use the HFACS-Eq framework to analyse more horse-related human accidents and 3) adopt the focus of an all-inclusive, *human-horse-environment triad* risk mitigation approach.

CRediT authorship contribution statement

Meredith Chapman: Writing – original draft, Visualization, Investigation, Conceptualization. **Kate Fenner:** Writing – review & editing, Supervision, Methodology. **Matthew J.W. Thomas:** Writing – review & editing, Supervision, Methodology, Formal analysis.

Data availability

Due to restrictions placed on the release and distribution of the data from the National Coronial Information System (NCIS) raw data associated with this research is not available for distribution.

Ethics statement

This study was reviewed and approved by 1) the Central Queensland University Ethics Committee with the approval number: (H17/02–026), dated (March 28, 2017) and 2) the Australian Justice Research Ethics Committee granting access to the NCIS database with the approval number: (CF/17/1380), dated (July 17, 2017).

Declaration of competing interest

We declare and believe there are no competing financial, personal interests or conflicts of interest associated that influence the work reported in the paper submitted for consideration and publication in Heliyon. This research project is/was supported under the Commonwealth Government's Research Training Program. I gratefully acknowledge the financial support provided by the Australian Government.

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