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The Comparative Measurement of Animal Welfare: the Cumulative Pain Framework

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Note: In the first edition of this book, the chapter was titled "The Comparative Measurement of Animal Welfare: the Cumulative Pain Framework." At that time, our primary focus was on the Cumulative Pain metric due to our profound concern for addressing the sources of suffering in animals. While the Welfare Footprint concept remained the ultimate goal, we centered our paper on Cumulative Pain as we believed, and continue to believe, in the urgency of alleviating animal suffering.

However, we recognize the importance of presenting a comprehensive measurement of animal welfare that extends beyond Cumulative Pain. Consequently, we no longer refer to Cumulative Pain as a standalone framework. The true framework encompassing all aspects of animal welfare measurement is the Welfare Footprint. This expanded framework not only includes Cumulative Pain and Cumulative Pleasure (alluded to in the first edition but not fully elaborated), but also integrates analytical efforts aimed at comprehensively addressing all sources of suffering within populations.

The presentation of this comprehensive framework in this revised edition is made possible by the maturation of the method, thanks to its application by us and other researchers, as well as valuable feedback from those who have used the method and participants in various workshops we have conducted. We extend our heartfelt thanks to all who have contributed to the development and refinement of this approach.

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Summary

We present a novel analytical framework for the description and quantification of pain in animals. Pain is operationally and broadly defined as ‘any felt negative affective state’, thus encompassing negative affective experiences of both somatic origin (physical pain) and more related to the primary emotional systems (psychological pain). The framework translates evidence on the duration and intensity of the pain associated with each welfare challenge (e.g. diseases, injuries, deprivations, fear) into time spent in five discrete categories of pain intensity using evidence from multiple disciplines (e.g. evolutionary biology, neurosciences, pharmacology). By considering the prevalence of each challenge in the population, typical times in pain are then determined for the average population member. The method is open to scrutiny, highlights existing knowledge gaps and incorporates uncertainty about model parameters. The use of time in pain as a universal metric enables comparing and combining the cumulative load of multiple and diverse negative events experienced over any period, or lifetime, and, at the populational scale, determining the welfare footprint of different production systems or animal-sourced products.

Why is it important to quantify pain and pleasure in animals?

The expansion of the animal population under human care has occurred at a great cost to their welfare, particularly in the last decades [1,2]. For example, productivity gains that increased the efficiency of meat, egg and dairy production arose predominantly through the selection of fast-growing and highly productive breeds. This has stretched physiological limits beyond natural limits, greatly increasing the incidence of metabolic, bone and joint disorders [3–6]. Additionally, housing systems involving the confinement of large groups of animals in barren conditions were adopted widely, depriving animals of the possibility to fulfill many of their behavioral and social needs [7].

To effectively improve the welfare of animals under human care, a clear understanding of the impacts of different management practices, genetics, and the environment on their well-being must

be established to determine which policies and interventions should be ascribed priority, so that prevention and alleviation efforts are effective.

Although different animal welfare assessment frameworks already exist (reviewed in [2]), a metric that quantifies negative affective states in animals is still lacking. Here we present an analytical framework developed to fulfill this purpose, which focuses on ‘felt negative affective states’ emerging from different conditions and hazards. **We operationally refer to any ‘felt negative affective state’ very broadly as pain** (Box 1.1), applying the term to experiences of both physical (physical pain) and psychological (psychological pain) origin (e.g., fear, anxiety, frustration, boredom, anger). The framework builds on concepts and modeling efforts used in global health [8], psychology [9] and animal welfare research [10–13] and is aimed at quantifying the cumulative load of the negative affective experiences of animals over any period of interest using a meaningful metric: time in pain. To this end, it translates evidence on the duration and intensity of the pain associated with each welfare challenge to which animals are exposed to time spent in painful states of different intensities. It strives to describe pain, both physical and psychological, in a way that is as truthful as possible to the individual animal’s experience, grounded on evidence of its manifestations, neurophysiologic knowledge and evolutionary reasoning.

Every sensory and conscious experience happens along a time dimension. Time is at the heart of how individuals experience life, so the use of a universal, time-based scale enables comparing and combining the impact of experiences of very different natures to determine the cumulative time in pain resulting from different practices, production systems, and interventions.

Box 1.1 Physical, Psychological and Cumulative Pain

For measurement purposes, we operationally refer to ‘**any felt negative affective state**’ (i.e. a state **experienced as unpleasant**), independently of its origin (or brain system involved [14]), simply as **pain**. Negative affective experiences with a somatic origin are referred to as ‘**physical pain**’ and include other affective states for which the term ‘pain’ is not commonly used, such as unmet physiological needs (e.g. thirst, hunger) and sensory signals perceived as **unpleasant** (e.g., loud noises, bright lighting). Negative affective states that are more related to the primary emotional systems [14] are operationally referred to here as ‘**psychological pain**’.

The new definition of pain introduced in 2020 by the International Association for the Study of Pain (IASP) now considers this possibility, stating that pain is “*an unpleasant sensory and emotional experience associated with, or **resembling** that associated with, actual or potential tissue damage*” [15]. Other authors also recognize the use of the term ‘pain’ to describe unpleasant experiences of mental origin (psychological pain) and acknowledge that tissue damage and nociceptive pathways are unnecessary to experience pain [16]. This is further supported by converging evidence on overlapping patterns of brain activation induced by both psychological and physical pain [16–18]. Importantly, this inclusive use of the term ‘pain’ enables easy recognition by the layperson (e.g., sorrow, grief and despair are frequently expressed as pain), and creates a unifying metric — time in pain — to directly compare unpleasant experiences of diverse nature and magnitude.

Cumulative pain — the key component of animal welfare assessed by this framework — is thus used as a time-based measure of the cumulative negative affective states experienced. We purposely avoid the term ‘**suffering**’ given its many uses [19], which range from any negative affective state to severe states accompanied by the perception of fear, anxiety, lack of control, or a threat to one’s sense of self [20,21]. Similarly, the term ‘**distress**’ is not used because it is typically restricted to more intense, frequent and/or longer-lasting aversive states [22–25].

The Cumulative Pain

The proposed analytical framework uses the ‘Cumulative Pain’ as a metric for loss of welfare. The Cumulative Pain is the total time individuals spend in pain (Box 1.1) of different intensities over a period of time or as the result of certain conditions. We refer to the analytical approach that determines such a burden as the ‘Cumulative Pain’ framework.

Time-based measures of well-being and health have been widely used outside the realm of the animal sciences. This is particularly true in development economics and global health research, where standardized time-based metrics are often used to measure the impact of injuries, diseases, deprivations and other adverse events on human populations. For example, disease burden is often measured based on the number of years of healthy life lost due to ill-health or to premature death (a metric known as disability-adjusted life-years) [26,27]. These time-based metrics represent a natural and direct measure of the experienced state of interest (or ‘experienced hedonic utility’ [9,28]), based on how individuals ‘felt’ during each period of interest.

Nevertheless those metrics, not being centered in capturing the affective states of individual, do not capture the dynamics of those states. The Cumulative Pain, on

The other crucial dimension of pain is its intensity [11,13,29][30,31]. Therefore cumulative pain experienced by an individual will be a function of both the intensity and duration of the adverse experiences, with longer and more intense negative states causing a greater negative impact on welfare. Both dimensions and the method to register them (and other aspects of the pain experience) will be explained in more detail below.

How much can it hurt? Defining categories of pain intensity

Pain is one of the most influential forces in animal evolution. It is a warning signal of real or perceived danger that must be noticeable enough to change behavior and prevent survival and reproduction from being compromised [14,32–34]. Generally, the greater the threat, the more intense the signal should be to ensure it has priority over other functions and behaviors under the individual's control [35,36].

Accordingly, more unpleasant sensations should generally be more disruptive, engaging more of the affected individual's attention [10,34,36–38]. For example, the degree of unpleasantness associated with severe lack of food, impaired oxygen intake, or imminent danger should be high enough to ensure that less critical ongoing behaviors and processes are put on hold until the threat is reduced or removed. The same applies to endogenous threats, such as injuries and disease, as changes in behavior (e.g., increasing resting time) are an important part of the coordinated response to enable healing and fight disease [39]. In general, behaviors that only improve long-term fitness, such as play, should be abandoned first, as attention and resources should be diverted to functions that are of critical value to fight or cope with the threat [14,39]. Therefore, we expect a positive association between pain intensity and the degree of disruption, which can be measured based on how much the pain disrupts an animal's attention from ongoing behaviors and tasks [10,37]. Such an association is also expected from a more mechanistic perspective, as higher intensities of pain are likely to interfere with the attentional processing of other tasks as they compete for attentional resources [40,41]. Furthermore, pain is also likely to interfere with cognition by impairing the ability to attend to and comprehend other cues, *'squeezing out other perceptual inputs and preventing cognitive processing'* [19].

Thus, we focus on (i) the **importance of the pain signal to promote adaptive behaviors** and (ii) the **disruptive character of the pain experience** to classify pain into four discrete categories of intensity [42]. The number of categories was devised to represent a good balance between scientific tractability and resolution, though there is no impediment to the creation of categories intermediate to those presented. Categorizing pain instead of measuring it on a numerical scale of intensity also prevents us from forcing ratings that may not necessarily be linear onto a linear scale. We intentionally avoid using the terms 'mild', 'moderate' and 'severe', as they have been extensively used in a wide variety of contexts with different meanings. Instead, we preferred to use terms that evoke an empathic appreciation of the intensity experienced and that could, in principle, be applied to different species, as follows:

Box 1.2 Definition of Pain Intensity Categories

No Pain:

Annoying: experiences of pain perceived as aversive, but not intense enough to disrupt the animal's routine in a way that alters adaptive functioning or affects the behaviours that animals are motivated to perform [54]. Similarly, Annoying pain should not deter individuals from enjoying pleasant experiences with no short-term function (e.g., play) and positive social interactions. Sufferers can ignore this sensation most of the time. Performance of cognitive tasks demanding attention are either not affected or only mildly affected. Physiological departures from expected baseline values are not expected to be present. Vocalizations and other overt expressions of pain should not be observed.

Hurtful: experiences in this category disrupt the ability of individuals to function optimally. Different from Annoying pain, the ability to draw attention away from the sensation of pain is reduced: awareness of pain is likely to be present most of the time, interspersed by brief periods during which pain can be ignored depending on the level of distraction provided by other activities. Individuals can still conduct routine activities that are important in the short-term (e.g. eating, foraging) and perform cognitively demanding tasks, but an impairment in their ability or motivation to do so is likely to be observed. Although animals may still engage in behaviors they are strongly motivated to perform (i.e., exploratory, comfort, sexual, and maintenance behaviors), their frequency or duration is likely to be reduced [55]. Engagement in positive activities with no immediate benefits (e.g., play in piglets, dustbathing in chickens) is not expected. Reduced alertness and inattention to ongoing stimuli may be present. The effect of (effective) drugs (e.g., analgesics if pain is physical, psychotropic drugs in the case of psychological pain) in the alleviation of symptoms is expected.

Disabling: pain at this level takes priority over most bids for behavioral execution, and prevents all forms of enjoyment or positive welfare. Pain is continuously distressing. Individuals affected by harms in this category often change their activity levels drastically (the degree of disruption in the ability of an organism to function optimally should not be confused with the overt expression of pain behaviors, which is less likely in prey species). Inattention and unresponsiveness to ongoing stimuli and surroundings is likely to be observed. Relief often requires higher drug dosages or more powerful drugs. The term Disabling refers to the disability caused by 'pain', not to any structural disability.

Excruciating: all conditions and events associated with extreme levels of pain that are not normally tolerated even if only for a few seconds. In humans, it would mark the threshold of pain under which many people choose to take their life rather than endure the pain. This is the case, for example, of scalding and severe burning events. Behavioral patterns associated with experiences in this category may include loud screaming, involuntary shaking, extreme muscle tension or extreme restlessness. Another criteria is the manifestation of behaviors that individuals would strongly refrain from displaying under normal circumstances, as they threaten body integrity (e.g. running into hazardous areas or exposing oneself to sources of danger, such as predators, as a result of pain or of attempts to alleviate it). The attribution of conditions to this level must therefore be done cautiously. Concealment of pain is not possible.

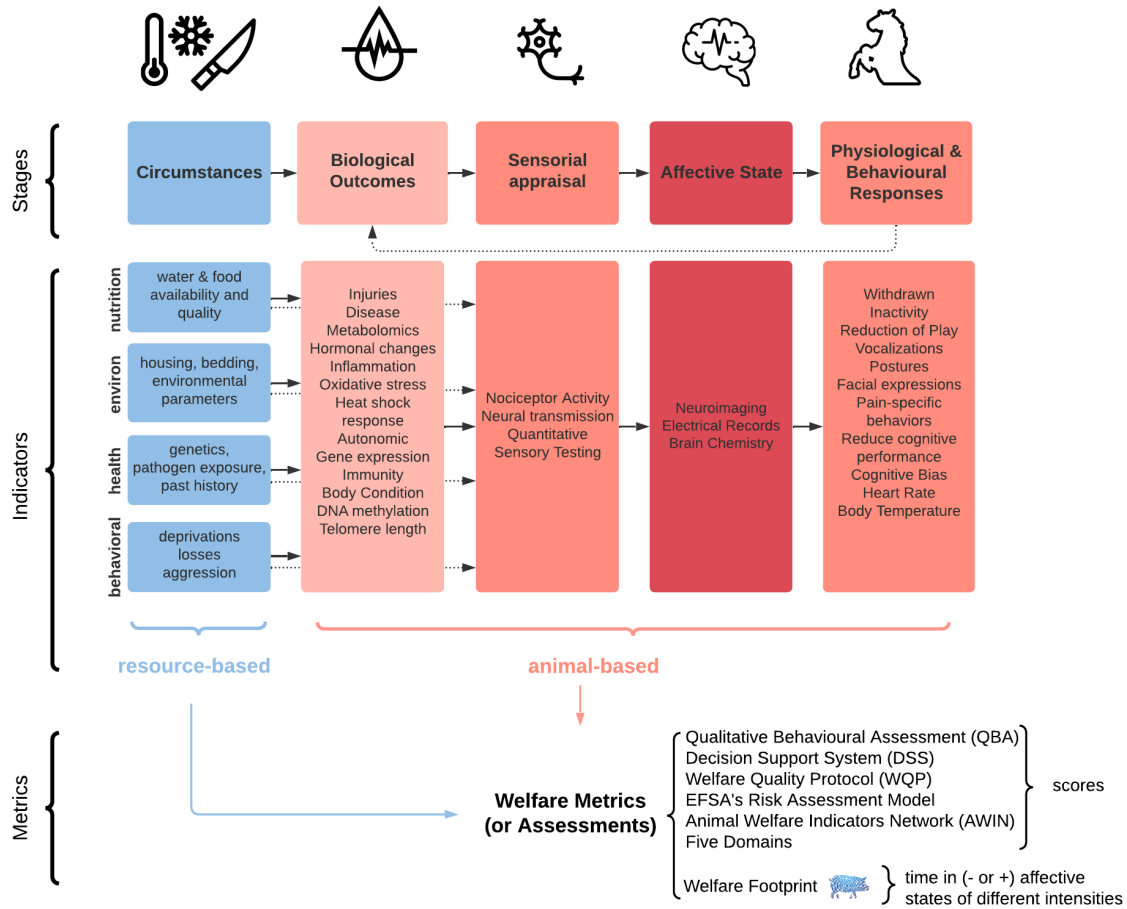
These categories should apply to experiences of physical and psychological pain. In the case of psychological pain, the intensity should similarly signify the corresponding degree of importance of the stimulus [14]. For instance, the rarer a critical resource (or the higher the cost to obtain it), the greater the unpleasantness (probably involving the three primary negative emotional systems [14]): Fear, Sadness, Anger) associated with its absence or loss is likely to be. For example, the psychological pain associated with the severance of the maternal bond would be higher for mammals with heavy parental investment, as in such cases a stronger emotional bond to the offspring is favored by natural selection. Likewise, intensity of fear should be greater with more imminent threats (e.g. the closer a predator or dominant conspecific) or more vulnerable victims (e.g., lack of cover or safe shelter).

How much does it hurt? Pain intensity attribution

To account for uncertainty in the classification of pain intensity, we propose treating the assignment of each intensity category as a hypothesis, using existing evidence to inform the probability that the pain belongs to each intensity category. Rather than deciding whether or not a painful experience is of a given intensity ('yes' or 'no'), the probability that the pain associated with a challenge belongs to that category is estimated based on the evidence available; the greater the strength and quality of the evidence towards a given intensity category, the greater the probability attributed to that category. For example, if play behavior is not affected in young animals experiencing a given welfare challenge, it's likely that the intensity of the pain is of an annoying nature, at least while the play activity lasts. In general, the greater the quality of the evidence and the higher the number of indicators of pain, the more certainty will exist about the intensity of pain experienced. Although this will rarely lead to a final verdict (estimates are always open to revision as knowledge advances), this process reduces uncertainty and channels debate into more explicit boundaries about the level of pain experienced as a result of each welfare challenge endured.

Naturally, how accurately different indicators of pain can predict individuals' experiences will vary depending on how closely they match the hedonic experience of the affected individual (Figure 1.2). Because we cannot directly assess hedonic experiences, affective states can be inferred by the associated responses of the organisms. If the adaptive value of pain is to prompt protective and adaptive behavioral responses, the use of behavioral indicators of pain seems to be the particularly suitable way to interpret the intensity of the pain experienced. The study of preferences and relative strength of motivation to obtain a resource is one of the most reliable means of inferring how a resource or environment may impact an animal's affective state. This is particularly true in the case of prey species, which have evolved to mask their pain. For example, measuring how hard an individual will work to obtain a particular resource can help establish the degree to which its deprivation is adverse [43–45].

Pain intensity attribution should, whenever possible, also be guided by evidence at other levels. Threatening and aversive conditions elicit several other coping responses, including the activation of the sympathetic nervous system and adrenal medulla, secretion of stress hormones, and mobilization of the immune system [46]. For example, after an injury, the activation of inflammatory processes suggests the presence of pain (proinflammatory cytokines can act directly on the nociceptive sensory neurons, changing their excitability and inducing their persistent sensitization). Similarly, the presence of causative factors (namely physical, chemical or biological conditions that are known to threaten, or be perceived to threaten the individual's welfare), may also suggest pain, even when the resulting physical or psychological offenses are not evident or observable.



Alonso WJ Schuck-Pain C. 2021 Metrics vs. Indicators: Clarifying Essential Concepts in Animal Welfare Assessment. welfarefootprint.org/2023/05/31/welfare-metrics-vs-welfare-indicators

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Figure 1.2. The major components of physical and psychological pain and the adaptive responses of the organism. Darker red tones represent more reliable (although, usually also the less accessible) indicators of hedonic experiences. For simplicity, feedback loops are not represented.

Pain assessments should be tailored to the responses typical of each species, and based on comprehensive knowledge of their behavior, life-history and physiology [33]. However, in cases where species-specific information is limited, we may assume that a welfare challenge causes similar pain in different species, given the vast homologies in the sensorial and neuronal make-up of many species. Similarly, the adaptive role of pain, in most cases, can be analogous [47]. This is a widely held assumption in translational research, which uses animal models to test the efficacy of painkillers and psychiatric drugs [48–50]. Indeed, evidence suggests a high level of homology in the physical manifestations of pain and how it is sensed across vertebrate species [51]. For instance, we can safely

assume that if a hen is scalded while fully conscious, she will experience pain at the excruciating level – the ‘paralytic perfectionism’ [52,53] that suggests that we do not have empirical evidence of the experience of such intense pain is not acceptable here. As expected, when the analysis is focused on highly derived traits (those exclusive of more recent phylogenetic branches), limitations arise [54–56].

To estimate the intensity of a specific pain-inducing experience we can also consider whether the affected individual would trade the sensation produced by a welfare challenge for another painful event with already established intensity. For example, the pain associated with exposure to extreme cold can reach a disabling level (avoidance of extreme cold is critical for survival). Pain at the disabling level could then be attributed to the pain of hunger felt by individuals willing to endure a disabling level of cold exposure to obtain food. This approach makes minimal external assumptions about the effect of this adversity (in this case hunger) on animals. In all cases, it is important to bear in mind that the classification of pain intensity aims to determine the ‘instantaneous’ intensity of the physical and/or psychological pain associated with a challenge, regardless of its duration (although longer lasting ailments may be perceived as more severe, their intensity is not necessarily higher). The temporal dimension of pain is addressed in the next section, along with a description of the framework used to track the evolution of pain intensity over time. Examples of how the approach is applied are provided throughout this book.

Making hypotheses explicit: the Pain-Track tool

Like many other biological phenomena, pain is a dynamic process that unfolds along a temporal dimension: it may develop and resolve gradually or suddenly, be brief or prolonged, constant or episodic. To describe and assess the intensity and duration of the pain caused by each welfare challenge, we developed a standardized visual framework, which we refer to as Pain-Track [42] (Figure 1.3). In the Pain-Track, the five categories of pain intensity are vertically ordered by their intensity. Time is segmented, where each segment delimits expected changes in pain intensity (pain phases). Since pain experiences can unfold over a wide range of periods (from milliseconds to years), time segments can be associated with different time units to ensure the required flexibility.

The Pain-Track is also designed to capture (i) situations in which uncertainty in the classification of pain intensity is present (i.e. it is not possible to determine with certainty to which level of intensity the pain belongs) or (ii) the temporal profile of pain at the population level, considering the expected variability in pain among individuals. Accordingly, for each time segment, intensity categories can be filled with either (i) the probability of pain intensity at each level or (ii) the estimated proportion of the population that experiences pain at each level. If stacked cells do not add up to 100%, the remaining percentage is attributed to a state of “no pain”. To incorporate uncertainty into the duration of segments, as well as the expected natural variability in the duration of the event of interest, the duration of each segment can be represented by an uncertainty range.

The Pain-Track in Figure 1.3 shows a hypothesis for the temporal evolution of the pain associated with an untreated skin wound suffered by a laying hen. In this example, there are four time segments: (i) the moment of wound infliction (tissue rupture); (ii) the period of hemostasis (coagulation), characterized by vasoconstriction, activation of the clotting cascade and the release of proinflammatory cytokines; (iii) the acute inflammatory phase; and (iv) the proliferative (repair) phase, when residual inflammation (hence pain) may also be present. In each segment, the intensity categories are assigned a probability that the pain during that period belongs to that category. At the

population level, the percentages in the cells may also be interpreted as the proportion of the population that experiences each level of pain, or the proportion of the time segment spent at each intensity level.

A detailed justification of the probabilities and durations shown in this Pain-Track is available in Chapter 4 [57]. For example, the adaptive value of rapidly preventing further tissue damage suggests that skin rupture should cause intense pain, even if short-lived (segment i). The painful nature of tissue rupture is also supported by the observation that nociceptive stimulation of the skin triggers an increase in blood pressure that is similar (both in terms of amplitude and duration) to known painful events [58]. After the first 12-48 hours — coinciding with the observation of the greatest levels of proinflammatory cytokines (segment ii) — pain should subside until it is predominantly annoying. Pain will likely last as long as there is residual inflammation (often up to two weeks), even if it is mild.

	i. Wound infliction Point of tissue rupture	ii. Hemostasis (coagulation)	iii. Acute inflammation	iv. Inflammation + proliferation
Excruciating				
Disabling	60%	20%		
Hurtful	40%	80%	70%	20%
Annoying			30%	60%
Duration	0.5 - 2 min	5 - 15 min	0.5 - 2 days	7 - 14 days

Figure 1.3 Pain-Track with hypothesis for the temporal evolution of the pain associated with a skin wound in a laying hen. Percentages represent the probability that pain is felt at each category of intensity (for the duration indicated in the bottom row). For analysis at the population level (e.g. hypotheses on the typical or expected evolution of pain intensity), percentages may also be used as the estimated proportion of the population that experiences pain at each level at each time segment. This figure does not represent the level of No Pain. Durations are represented by a range reflecting both the uncertainty and natural variability in expected values. For a detailed justification of all hypothesized parameter values, see Chapter 4 [57].

Time segments should be used to characterize a fairly homogeneous experience level of the pain felt by an individual over time (or, where appropriate, the estimated proportion of the population that experiences pain at each level). Therefore, time segments may not necessarily match the duration of tissue healing phases or the temporal dynamics of physiological indicators of stress. For instance, within the same healing phase, an individual may experience pain at different intensity levels (e.g. the acute inflammatory phase of a disease may be composed of multiple sub-phases, wherein pain progressively subsides, hence several time segments will be needed. Conversely, pain may cease before or long after healing is complete. For example, a distinguishing feature of the pain associated with burning events is the observation that pain often persists long after healing [59].

Each numerical input displayed in a Pain-Track should be based on a comprehensive review of knowledge gathered from different disciplines and sources. In addition to organizing and summarizing knowledge, Pain-Tracks require that assumptions about the intensity and duration of the pain typically associated with each welfare challenge are made explicit, thus facilitating scrutiny

and debate. Because evidence used to fill in the Pain-Track will be often limited, criticism of the proposed values is encouraged to drive targeted progress.

For stress-testing and to make this analytical approach also available in the medical field, this framework was initially developed for the assessment of pain in human patients [42]. To encourage its use by clinicians and researchers, a user-friendly web application of the framework was also developed, and is available for free at <https://Pain-Track.org>. In this book, we use this approach to evaluate the different welfare challenges that commercial laying hens endure. All Pain-Tracks presented in the book are available at <http://Pain-Track.org/hens>, where users can test alternative values for all parameters (e.g. pain intensity, duration, prevalence and frequency of each challenge) and test how their choices would affect the estimated time in pain endured.

Pain interaction and modulation

The effects of different welfare harms are not necessarily independent of each other [31,60], the different ways that negative affective experiences interact physically and psychologically should be considered. This topic is far complex to be addressed here with its deserved attention, but suffice to mention that it does need to be considered given its high impact in the experience of pain. For example, evidence indicates that early traumatic experiences in vertebrates (including humans) are associated with long-term alterations in coping style and responsiveness to stress. This altered coping style can contribute to the development of fear, anxiety, and other mental health impairments later in life [31,61]. Accordingly, painful procedures and highly stressful experiences endured at an early age can increase the likelihood and/or intensity of the pain associated with other harms (e.g., beak trimming in newborn chicks, and routine mutilations performed on piglets right after birth, such as surgical castration, tail docking, and teeth trimming).

Cumulative pain at the population level

Although pain inherently concerns individuals, we operationally accept that the collective welfare of the members of a population can also be determined. Measuring cumulative pain at the population level is also necessary to account for the heterogeneity in the exposure of population members to different welfare challenges; not all individuals will experience every challenge. For example, while injuries such as keel bone fractures are widespread among laying hens, events such as fatal cannibalistic attacks are only experienced by a few individuals. Therefore, measurement efforts must consider the prevalence of each welfare challenge, so that the resulting pain is determined for the average member of the population (which may not necessarily correspond to any real organism). For example, while injuries such as keel bone fractures are widespread among laying hens [62], events such as fatal cannibalistic attacks are only experienced by a few individuals [57]. Still, if this heterogeneity is the main factor of interest in a particular study, we suggest subdividing the population into additional life-fates. For example, in the case of laying hens, they could be subdivided into those that experience cannibalistic attacks and those that do not.

At the population level, the time spent at each level of pain intensity as a result of each welfare challenge is therefore determined by multiplying it by its prevalence. For example, if a bone fracture causes approximately 10 hours of acute pain at a disabling level, and 70% of the members of a population fracture this bone at some point in their lives, then the average member of this population could be said to experience 7 hours of disabling pain due to this bone fracture.

Measurements at the population level also enable determining and comparing the impact of different practices and conditions across demographics, geographies and time.

Should we aggregate pain intensity levels?

To what extent can comparisons involving different levels of pain intensity be made? Would 100 hours of disabling pain be equivalent to 1 year spent with a hurtful sensation? How long could an individual endure annoying pain to make it equivalent to a few minutes of excruciating pain? For analytical simplicity, it would be very convenient if a time-based equivalence could be found between the levels of pain.

Yet, we are still far from understanding the numerical relationship among the intensity categories in terms of the degree of unpleasantness that they cause. Given the current lack of objective ways to numerically compare pain levels, we suggest that analyzing the total time spent in each category of pain intensity (over a period of interest) represents a more accurate, transparent and robust approach, grounded in explicit parameters with biological meaning. First, by keeping intensity categories disaggregated, no information is lost. If at some point the mathematical equivalence (in time units) between intensity and duration can be determined, the disaggregated results are readily available for establishing a putative (unique) measure of pain (or suffering/distress; Box 1). In fact, this approach might prove to be more informative and insightful as it allows researchers and decision-makers to evaluate the impact of different practices, policies and reforms along a scale of negative experiences. For example, while some policies and reforms may have a large impact on minor (annoying) pain, others may mitigate the most extreme (excruciating) pain experiences. By clearly differentiating these effects, the pursuit of different priorities, such as relieving the worst kinds of preventable suffering [63], becomes possible.

Additionally, there is a deep philosophical and ethical puzzle regarding the validity of balancing different levels of suffering in comparisons involving different individuals [64]. For example, if a fraction of individuals in a population endure disabling or excruciating pain should they be scored similarly to a population where no individual suffers severe pain, but a larger fraction of individuals experience annoying or hurtful pain for a longer time? As discussed by Anderson [20], *“single aggregate numbers intended to represent ‘amount’ of suffering cannot be used reliably to determine priorities and make decisions, because they don’t capture the urgency of discrete instances of suffering”*.

Incorporating and exposing uncertainty

The process of mapping welfare challenges into categories of pain intensity, establishing their duration, and determining their prevalence in a population, is fraught with uncertainties. To date, little is known about the clinical evolution of many of the diseases and injuries animals experience.

Additionally, we also expect a high degree of heterogeneity in the prevalence of each welfare challenge due to true differences in predisposing factors, such as handling practices, human-animal interactions, genetics and other environmental factors [2,65].

To incorporate and expose the uncertainty of each parameter's value into the estimates, each parameter should be represented by a range reflecting both its uncertainty and variability, instead of (unrealistically) precise point estimates. Parameters describing the duration, number of occurrences, and prevalence of each welfare challenge should therefore be represented by an uncertainty interval. For estimates of pain intensity, the framework guides assessment through specific criteria defining each category of intensity. However, evidence guiding this process will often be lacking, and different indicators may provide conflicting results. Therefore, instead of assigning the pain from a process (e.g., acute inflammatory phase of a bone fracture) to a fixed intensity, the framework estimates the probability that it belongs to each of the intensity levels (as we saw previously, Fig. 1.3).

In our application of the model, the uncertainties associated with the estimated values of each parameter are then propagated through the model in a way akin to a Monte Carlo simulation. Final estimates of the time spent in each level of pain intensity should therefore enable assessment of how confident one can feel about the result. The sensitivity of the estimates to all parameter value choices used in this book can be verified at <https://Pain-Track.org/hens>.

Conclusion

Building upon previous modeling efforts [8,9,11,31], we propose an analytical framework that is transparent, simple, and scalable. The Cumulative Pain Framework quantifies negative welfare in animals based on the duration and intensity of diverse unpleasant states. . It also refocuses the welfare debate towards the quantification of the “Affective state” of sentient animals, providing a platform where hypotheses about the duration and intensity of pain associated with negative affective experiences must be made explicit, and where disagreements with proposed values are a driver of progress. The current approach also contributes to existing animal welfare assessments [2] by providing evidence-based estimates of the cumulative pain experienced by individuals or populations impacted by specific genetic, environmental or management factors.

This perspective is also at the core of most research on the valuation of human health and welfare, and forms the basis of various policies guiding efforts at poverty alleviation and disease mitigation [8,66,67]. . However, unlike metrics in global health [10], we only assess experienced hedonic states (time in pain) and, deliberately do not attribute any value to deprivation of the time of life due to premature death in our estimates, as for animals without a life ‘worth living’ [36], increments of time in life cannot be computed positively .

The framework also provides a foundation and natural metric for the development of a **welfare footprint** of livestock products [68] and other industries that use animals. Nevertheless, the Welfare Footprint needs to be addressed in a different document, as it depends more than the welfare metric (to which we propose the Cumulative Pain), but also contains provisions be comprehensive regarding the animals considered (including discarded, breeders, etc) and be of easy and quick interpretation by consumers to facilitate its broad adoption

Good animal welfare also implies the experience of subjective affective states of a positive valence [36,69–72]. Although the framework considers how the deprivation of positive experiences gives rise to negative states (e.g, frustration from the deprivation of highly motivated behaviors), it can be expanded in the future to facilitate the quantification of the time spent in positive affective states. .

It is our hope that the findings emerging from this endeavor will provide a more comprehensive understanding of the impact of decisions on animals' lives, a platform for productive collaboration between experts from different fields, and a blueprint for the measurement of pain wherever it is present.

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