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Article

Cumulative Pain: An Evidence-Based, Easily Interpretable and Interspecific Metric of Welfare Loss

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Simple Summary: Of the following practices, which is associated with more suffering: the surgical castration of piglets without pain control, or the extreme confinement of their mothers in gestation crates? And how do these practices compare with the pain associated with some forms of slaughter, with the highly prevalent fractures of the keel bone in egg-laying hens, or the chronic state of hunger that broiler breeders typically endure? More than scientific curiosities, these questions are relevant for the effective allocation of time and resources to policies and reforms aimed at improving farm animal welfare. Here we describe a recently developed approach that makes these assessments possible, the Cumulative Pain metric. The approach translates evidence on the duration and intensity of the unpleasantness (broadly referred to as 'pain', either physical or psychological) associated with one or more welfare challenges into time spent in four categories of pain intensity. The use of time in pain as a universal metric enables comparing and combining the cumulative load of negative experiences endured over any period and provides the basis for the development of welfare footprints of animal-sourced products.

Abstract: We describe a recently developed approach to quantify welfare loss in animals, the Cumulative Pain metric. It combines the two most relevant dimensions of negative affective experiences: intensity and duration. The metric enables estimating the time individuals spend in negative affective states of a physical or psychological nature (operationally referred to simply as 'pain') of different intensities as the result of one or more challenges (e.g., diseases, injuries, deprivations). A new notation protocol (the Pain-Track) is used in which the duration of the experience is represented along the horizontal axis and intensity is represented by four categories in the vertical axis. Pain experiences are partitioned into temporal segments, where hypotheses for the experienced duration and intensity are proposed based on existing welfare indicators (e.g., neurophysiological, behavioral, anatomical, evolutionary). This structure forces transparency about assumptions and uncertainties, highlights knowledge gaps, and enables estimates to be continuously adjusted. Because the Cumulative Pain metric is based on parameters with a broadly common biological meaning, it provides the much needed interoperability among assessments of animal welfare. It enables comparing the impact of practices and living conditions, policies and interventions, and the calculation of welfare footprints of animal-sourced products using a universal measurement unit.

Keywords: animal welfare; pain; farm animals; Pain-Track; Cumulative Pain; pain assessment; welfare footprint; time; interspecific comparisons

1. Introduction

Because inner mental phenomena and affective experiences are not directly accessible to measurement, decisions aimed at improving the quality of life of animals under human custody are widely guided by indirect indicators (e.g., behavioral, neurophysiological, evolutionary) and subjective assessments of their well-being [1–6]. Requirements for minimum space allowances, enrichment, access to outdoor environments, stunning prior to slaughter and bans of practices involving bodily mutilations all assume the possibility of inferring both the direction and magnitude of welfare that is changed by these

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provisions. The common objection to animal welfare approaches centered in the assessment of affective states (the feeling school, [1]), which argues that subjective states are not available to scientific inspection, is in fact contradictory: without assuming that, to a certain degree, one can infer the direction and extent to which practices such as the above impact animals' inner experiences, no prioritization of action would ever be possible.

If such inferences are made at a level that is sufficiently precise for practical matters, much could be gained from the use of approaches that make these inferences, and their supporting evidence, explicit. Indeed, if one accepts that the valence and magnitude of affective experiences are an objective reality that leaves a trail of scientifically accessible indicators, efforts to grasp this reality in a transparent and mathematically treatable manner can greatly facilitate our understanding of how much good can be achieved by different policies and interventions. Here we propose the use of a universal metric, with common biological meaning, that fulfills this purpose.

2. The Cumulative Pain metric

While several approaches have been developed to assess the welfare of farmed animals [1,5,7–9], they were not designed to capture an important element of any positively or negatively valenced experience: its duration. Whichever their nature or origin, the experience of any affective state extends over a certain period, be it a few seconds, days, months or years. Affective experiences will be also determined by their intensity, which typically change over time. The Cumulative Pain metric captures both these dimensions. It is aimed at representing the cumulative time spent in unpleasant (negative) affective states of different intensities as a result of one or more welfare challenges (e.g., diseases, injuries, fear, deprivations; [10]) over any period of interest, or over a lifetime.

Considering the importance, and greater urgency, of preventing animal suffering [11–13], under which positive welfare is unlikely, the metric is focused on the quantification of negative affective states (although the same approach could be employed to measure affective states of positive valence). We use the term 'pain' in its broader sense, as a synonym of 'negative affective state'. Physical pain is used to refer to negative affective states of a somatic origin and includes states for which the term pain is not commonly used, such as the unpleasantness associated with unmet physiological needs (e.g., thirst, hunger) and certain sensory signals (e.g., cold, loud noises). Negative affective states that are more related to the primary emotional systems [14], such as fear, anxiety, frustration, boredom, and anger, are operationally referred to as psychological pain [15,16].

Pain intensity is estimated based on existing welfare indicators (e.g., behavioral, physiological, neurological [1,6]), as well as knowledge of the importance of the pain signal to promote adaptive behaviors and of the pain-generating mechanisms involved in each challenge. Pain is an influential force in evolution, a warning signal of real or perceived danger that must be noticeable enough to change behavior and prevent survival and reproduction from being compromised [14,17–19]. The greater the threat, the more intense the signal should be [20,21]. Accordingly, more unpleasant sensations should generally be more disruptive, engaging more of the individual's attention [19,21–24]. For example, the degree of unpleasantness associated with severe lack of food 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. 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 [25]. 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 of critical value [14,25]. Higher pain intensities should also be more disruptive for interfering with the attentional processing of other tasks [26,27] and impairing the ability to comprehend other cues [28]. Four discrete categories of intensity are proposed (Table 1), though there is no impediment to the creation of intermediate ones. Categories are defined using descriptors and criteria to make them as relatable, unambiguous, and objective as possible (Table 1).

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For each welfare challenge an animal endures, the intensity of the pain experience will typically vary over time, with periods of relative homogeneous intensity interspersed with variations (of greater or lesser intensity) that characterize most episodes of pain. Therefore, the period during which the pain experience lasts can be segmented accordingly. For example, a hypothetical pain episode caused by a management procedure (e.g., a bodily mutilation) could be described as a sequence involving a few minutes of Excruciating pain, followed by a few hours of Disabling pain, some days of Hurtful pain, and a couple of weeks of Annoying pain alternated with brief moments of Hurtful pain. In this simplified example, the Cumulative Pain endured by an affected individual as a result of this challenge would be simply the sum of the time spent in pain of each intensity.

Table 1. Criteria defining the four discrete categories of pain intensity.

Category	Defining criteria
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 behaviors that animals are motivated to perform. Similarly, Annoying pain should not deter individuals from enjoying pleasant experiences with no short-term function (e.g., play) or 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. Vocalizations and other overt expressions of pain should not be observed.
Hurtful	Experiences in this category disrupt the ability of individuals to function optimally. 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. Although animals may still engage in behaviors they are strongly motivated to perform (i.e., exploratory, comfort, sexual, and maintenance), their frequency or duration is likely to be reduced. Engagement in positive activities with no immediate benefits (e.g., play in piglets, dustbathing in chickens) is not expected. Reduced alertness to ongoing stimuli may be present. The effect of (effective) drugs (e.g., analgesics, psychotropic drugs for 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 events associated with extreme levels of pain 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 criterion 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). Attribution of conditions to this category must be done cautiously. Concealment of pain is not possible.

3. Making hypotheses and assumptions explicit: the Pain-track tool

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To describe the proposed hypotheses about the intensity and duration of the pain caused by each welfare challenge, we developed a visual notation tool which we refer to as Pain-Track [29]. A blank Pain-Track is very similar to a musical staff, with horizontal lines representing the passage of time. Pain intensity categories are vertically ordered. Time is segmented, where each segment delimits expected changes in pain features, chiefly intensity. Since pain experiences can unfold over a wide range of periods (from milliseconds to years), time segments can be associated with different time units for greater flexibility. The pain experience can be described along the temporal axis with a simple line, as shown in Figure 1.

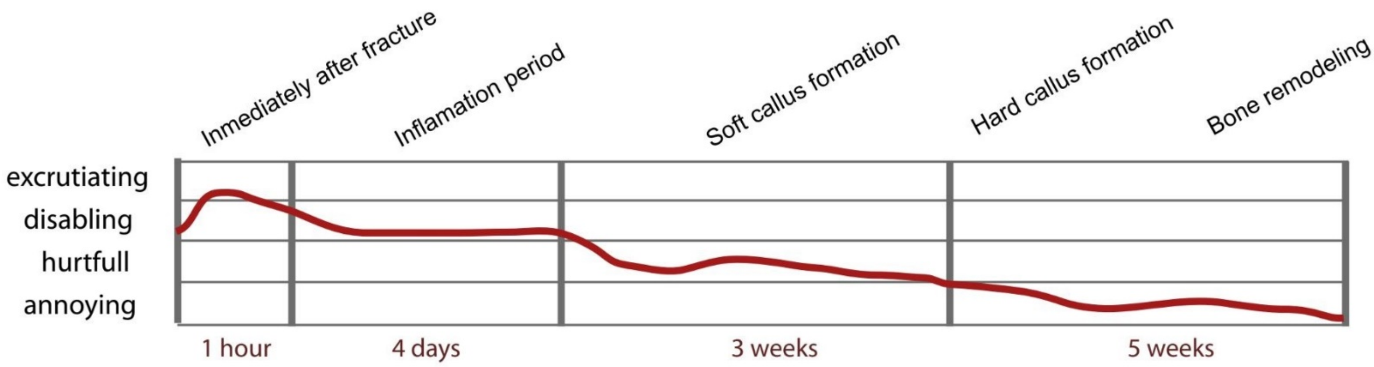

Figure 1. Example of Pain-Track (in 'path mode') describing the temporal evolution of the pain associated with a leg fracture in a human patient. This description illustrates the use in the clinical setting. Parameter values and justifications are available in [29], as inferred by the pediatrician and anesthesiologist Dr. Pedro E Salinas Salazar, MD (permission granted to reproduce figure from [29]).

More often, however, particularly in the case of non-verbal individuals (as is the case of animals), much uncertainty will be present in the attribution of intensity to one of the four categories. Indicators of pain will be often unreliable or non-specific, with existing variability in the way pain is felt by different individuals adding to the problem. To make this uncertainty explicit in the Pain-Track, existing evidence is used to inform a probability that the pain belongs to each of the four categories of intensity (chance mode, Figure 3). Probabilities can be interpreted as the weight given to the hypothesis that pain is of a given category. If stacked cells do not add up to 100%, the remainder percentage is attributed to a state of 'no pain'. Uncertainty regarding each probability can also be represented by using a range instead of a point estimate. Likewise, uncertainty may also be present regarding the duration of the time segments and, accordingly, be represented by uncertainty intervals.

The structure of the Pain-Track enables organizing existing knowledge to support or challenge the values proposed. The greater the strength and quality of evidence that a given painful state matches the criteria defining one of the intensity categories, the greater the probability attributed to that category. For example, burn pain is recognized as one of the most severe types of pain, comprising nociceptive, inflammatory, and neuropathic components [30,31]. In burning and scalding accidents with people and animals, bystanders have often reported that victims stayed conscious throughout the several minutes the experience lasted, screaming, calling for help, or trying to escape [32,33]. Similar reports exist for witnesses of punishment and torture by boiling [34,35]. Thus, assuming Excruciating pain until death or complete damage of nerve endings would not be unreasonable [36,37]. In other cases, the only certainty is that pain is 'not' of a specific intensity, with no elements to distinguish between the remaining categories (in such cases, the same probability is assigned to each of the plausible categories). In all cases, what Pain-Track authors

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do is to propose an initial hypothesis for the intensity and duration of pain in each segment of a Pain-Track, making supporting evidence and arguments readily available for criticism. These assessments can be made more precise as knowledge becomes available, or they can be challenged, helping drive targeted progress.

4. Case study: the welfare impact of keel bone fractures in egg-laying hens

Bone fractures are among the most serious welfare problems affecting laying hens in modern egg production [38,39], with the keel bone (the prominent ridge that serves as the point of attachment for the wing muscles; Figure 2) being particularly prone to damage.

Figure 2. Illustration of a typical fracture of the keel bone in a laying hen. The fractured site is located in the caudal third of the bone, the most frequently affected region. For reference, the recreation of a surgery with access to the fracture site is shown in color. Illustration: Olga Kurkina.

Here we focus on the pain associated with keel bone fractures to illustrate how, by using the Pain-Track structure, knowledge from different disciplines can be organized to formulate hypotheses about the intensity and duration of the pain associated with a challenge of interest. For simplicity, we consider the case of a fracture that heals completely, as evidence suggests this is the most common outcome following this type of fracture [40]. The intensity and duration values proposed in Figure 3 are justified in Table 2.

PAIN-TRACK	point of fracture	Inflammatory response i	ii	iii	callus formation
Excruciating					
Disabling	80-100%	70-90%	40-60%	20-40%	
Hurtful	0-20%	10-30%	40-60%	60-80%	40-80%
Annoying					20-60%
duration:	0.5 - 2 hours	1 - 2 days	1 - 2 days	2 - 3 days	2 - 12 weeks

Figure 3. Pain-Track (in 'chance mode') depicting hypotheses for the temporal evolution of the pain of a keel bone fracture with complete healing in laying hens. The justification for parameter values is available in Table 2. Where time units are expressed in units other than hours (days and weeks) only the time spent awake is considered (in this example 16 hours awake/day [41]).

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Table 2. Justification for the hypotheses of intensity and duration of the pain associated with a keel bone fracture that heals completely in egg laying hens, as described in the Pain-Track of Figure 3.

Segment	Justification for the hypotheses proposed
Point of fracture	Pain at this point is attributed to the activation of mechanosensitive nociceptors in the bone and surrounding tissues. In humans, this translates into a sharp and pierce pain at the time of injury [42]. Intensity is most likely of a Disabling nature (Table 1), as pain prevents most activities and strong analgesia is required. In mammals, the periosteum has an extremely dense sensory and sympathetic innervation, in which most of the mechanosensory fibers activated after a fracture are located [43]. As in mammals, it is adaptive for birds to experience intense pain during the initial moments of a severe fracture to ensure the reduction of movement needed for healing and protect the site from further injury. Additionally, avian and mammalian nociceptors are extremely similar [44–46]. Thus, we suggest that hens experience similarly acute pain. Initiation of inflammation/swelling is estimated to take 0.5-2 hours.
Inflammatory phase (i, ii, iii)	After the injury, an influx of inflammatory cells to the fracture site results in the release of inflammatory mediators that cause swelling (and further pain through activation of pressor receptors) and activate undamaged nociceptors [47–49]. Sensitization of the peripheral and central nervous systems may also lead to increased sensitivity to pain [48,49]. During the initial inflammatory phase, which in humans peaks after 24 to 48 h [50] and lasts about seven days, bone fractures are reported as acutely painful. Evidence for laying hens and other avian species suggests a similar process. For example, in hens with fractured keels, the expression of inflammatory factors is increased in the brain, liver, and abdominal muscle [51]. Intense pain is also adaptive at this phase: in addition to constraining movement to facilitate healing, increased resting helps counterbalance the greater metabolic demand [52–54]. Evidence from a model of post-fracture pain in pigeons also suggests that this phase is very painful in birds [49]. In this study, postoperative pain was evaluated for four days following osteotomy of the femur (immobilized by pins). Pigeons with no post-surgery analgesia spent significantly less time perching, and greater time lying on the floor, on days 1 and 2. Exploratory behavior was reduced, and resting time increased, across all days. Alertness also decreased substantially. The substantial changes in behavior and alertness on day 1 are compatible with the Disabling intensity, with intensity then gradually subsiding. However, because in hens fractures are not immobilized as in this study, pain is likely to last longer at more intense levels. Also, because the keel bone anchors the wing muscles, reactivation of mechanosensory fibers can occur even during respiratory motion [38]. As healing in birds is believed to be similar to mammals [55], we assume the inflammatory period lasts 4-7 days before a callus starts forming.
Callus formation	As inflammation decreases, pain and functional impairment subside as a callus starts to form. This process is carried out by chondrocytes and fibroblasts, which are stimulated by the expression of several growth factors and other elements that promote cell proliferation and cartilage formation [56]. These elements also participate in the activation of the painful path associated with the fracture [57]. Pain is thus likely during callus formation and bone remodeling. Some biochemical mediators of this process, such as members of the Bone Morphogenetic Protein (BMP) family, also have the ability to activate pain pathways [58]. Indeed, expression of BMPs at the injury site is often linked with persistent pain in fractured human patients. Evidence on the intensity of pain endured by birds is more scarce. However, we tentatively suggest that pain intensity is similar to that in mammals, subsiding gradually until bone remodeling is complete. Once a soft callus starts forming, healing should last on average 7 weeks, as based on a radiographic evaluation [40] reporting that 85% of keel fractures took an average of 7 weeks to heal. In this study less than 11% of complete healed fractures required more than 12 weeks. Thus, we assume that a uniform range of 2 to 12 weeks should describe the healing period for most fractures. The minimum estimate of 2 weeks is based on a radiographic study that monitored healing of naturally occurring keel fractures in hens [47].

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Cumulative Pain (Figure 4, column at the right) is obtained by summing the time in pain in each segment and pain category. To determine times in pain at each temporal segment, probabilities in each cell (Fig.3) are multiplied by the durations of the corresponding segment (bottom rows in Fig.3). The uncertainties associated with estimated parameter values are propagated through the model, so final estimates are presented with intervals to enable assessment of how confident one should feel about the results.

TIME IN PAIN

	point of fracture	Inflammatory response i	ii	iii	callus formation	CUMULATIVE TIME IN PAIN
Excruciating						
Disabling	0.5-1.8 h	13-26 h	8-17 h	7.7-17 h		**35-54 h**
Hurtful	0.06-0.3 h	2.3-8.2 h	8-17 h	22-35 h	200-940 h	**240-990 h**
Annoying					98-640 h	**98-640 h**

Figure 4. Estimated time in pain (hours) in each time segment and pain category. Estimates are the product of probabilities and durations as described in the corresponding cells of the Pain-Track of Figure 3.

In those cases where many welfare challenges are experienced, we similarly assume that cumulative pain is best represented as the sum of the time spent in pain due to each challenge [59–62]. This assumption is supported by evidence of an additive (independent) effect of multiple challenges on biological functioning, as observed in pigs [63], broilers [64,65] and laying hens [66]. Still, non-additive effects (e.g., such as observations that early traumatic experiences may change responsiveness to stress later in life [60,67], increasing the likelihood of other challenges) are also accounted for, as estimates are based on empirical evidence of the actual prevalence of challenges (and their symptoms) across all life phases.

5. Cumulative Pain at the population level

Cumulative Pain is a particularly powerful tool to guide campaigns and industry reforms when its calculation extends to the population level [41,68]. Naturally, not all members of a population will experience every welfare challenge. For example, while injuries such as keel bone fractures are widespread among egg laying hens [69], events such as fatal cannibalistic attacks are only experienced by a few individuals [69]. It will often be through differences in the prevalence of the many welfare challenges animals encounter during their lives that their welfare will differ across production contexts, geographies and time.

At the population level, the time spent at each level of pain intensity as a result of each welfare challenge must be determined by considering its prevalence too. For example, if keel bone fractures were estimated to affect 30-70% of hens in cage-free aviaries, then the average hen in a cage-free aviary (which may not necessarily correspond to any real individual) would be estimated to experience 50-470 hours of Annoying pain, 120-790 hours of Hurtful pain and 12-46 hours of Disabling pain due to this type of fracture (the product between prevalence and Cumulative times in Pain shown at Fig.4). Naturally, uncertainty and variability regarding the prevalence of challenges in the population of interest (in this example represented by the range 30-100%) is considered too.

6. Uses of the Cumulative Pain metric

The possibility to quantify the loss of welfare experienced by animals using a common metric (time in pain of different intensities) enables the comparison of practices and living conditions, along with the assessment of the most effective courses of action to reduce animal suffering. Measurements can focus on a single welfare challenge or industry practice (such as the surgical castration of piglets and the burden of pain avoided with replacement of this practice by immunocastration), or encompass several harms experienced under one or more contexts of interest. This enables comparing production systems in terms of the welfare loss they typically cause, identifying hotspots of suffering and estimating the welfare impact of policies and reforms.

For example, the Cumulative Pain metric has been used to quantify the impact of cage-free reforms, as measured by the total time in pain averted per hen raised in an aviary instead of a cage [41]. By analyzing the time in pain caused by challenges such as the deprivation of motivated behaviors, bone fractures, feather pecking and reproductive disorders, the analysis found cage-free aviaries to be clearly superior (with around 60% less time in pain of all intensities) to conventional and furnished cages [41]. In another study, the same approach was employed to explore how adoption of programs such as the Better Chicken Commitment and use of slower-growing breeds affect the welfare of broiler chickens [68]. The results, which included analyses of the time in pain due to lameness, cardiopulmonary disorders, behavioral deprivation and thermal stress, pointed to a net positive effect of the standards on welfare, with a reduction of at least 66%, 24% and 78% of the time in Disabling, Hurtful and Excruciating pain, respectively, relative to a conventional scenario based on the use of fast-growing broiler breeds.

The Cumulative Pain metric also enables determining the welfare footprint of animal-sourced products, defined as the cumulative time in pain due to all aversive experiences endured during production, per unit of animal product. To this end, it is necessary to consider all challenges typically experienced, from birth to death, of all types of individuals involved in the production process. For example, should we wish to determine the welfare footprint of an egg (i.e. time in pain embedded in each egg), we would need to consider the loss of welfare of all 'life-fates' [70] (e.g., layers, breeders, male chicks and individuals that die before slaughter) and all production phases (from the hatchery to the slaughterhouse). Next, estimates must be expressed in units of animal product (e.g., kilograms, pounds, liters, units) by considering the proportion of individuals of each type and their respective productivity. Through this standardization, a pound of a product will represent, in some cases, the pain endured during only a fraction of the life of one individual (e.g., cattle beef), while in other cases the same product weight will represent the Cumulative Pain endured by several individuals (e.g., small fish such as the yellow catfish, European perch and silver barb).

Finally, the Cumulative Pain metric also enables defining animal welfare in an empirically-grounded manner, with welfare being 'inversely proportional to the Cumulative Pain experienced'. This definition is aligned with suffering-focused ethical views, such as negative (or negative-leaning) utilitarianism, or any approach that considers the mitigation of suffering pivotal to welfare. Given the comprehensiveness of the concept of pain used, it is also consistent with other approaches in the study of animal welfare, including the classic five freedoms [10] (the more freedoms are violated, the greater the Cumulative Pain), or concepts associated with the capacity of animals to cope with their environment [71] (the greater the coping ability, the lower the Cumulative Pain). Yet the definition could be expanded to include positive affective experiences too, with welfare becoming 'inversely proportional to the Cumulative Pain and directly proportional to the Cumulative Pleasure experienced'. Although the latter might be more truthful to the full range of experiences an animal endures, and their combined contribution to well-being, its practical use is hindered by the challenges to establish the equivalence between positively and negatively valenced states (e.g., how much time of pleasure would be necessary to compensate an hour of torture-like pain?)

7. Conclusions

Time in pain is a universal metric that most people can relate to, not an abstract concept. It is a parameter with a broadly common biological meaning, which provides the much needed interoperability among assessments of animal welfare. It enables comparing

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the impact of welfare challenges across individuals, populations, production contexts, and even among different species, thus fostering the investigation of the equivalence of affective capacity among sentient species (a prerequisite in the interspecific comparison of welfare for practical purposes, e.g., allocation of funding for reforms) [72]. The framework also refocuses the welfare debate towards affective experiences at the individual level [73], providing a platform (the Pain-Track) where hypotheses about the duration and intensity of the unpleasantness associated with each of different welfare experiences are made explicit, and where disagreements with proposed values are a driver of targeted progress.

The Cumulative Pain metric also provides a foundation for the development of a welfare footprint of livestock products [74] and other animal-sourced practices. Like the creation of footprint measures in other contexts (e.g., water footprint), the development of an animal welfare footprint may raise awareness about the ethical impacts of economic activities involving animals, promote accountability and foster improvement. For example, the framework can inform consumers of the ethical impacts of their purchasing choices. The standardization of welfare assessment provided by a time-based metric can also provide a common framework for national and international certification schemes [75], enabling the comparison of different standards. A metric of the cumulative time in pain embedded in different products is also needed to inform policies and decisions in other areas, such as health or environmental sustainability [74]; to ensure that such decisions are not implemented at the expense of animals, a comparable measure of their impact on the welfare of animals is required [74].

Naturally, the Cumulative Pain metric can be elaborated in future developments. For example, good animal welfare also implies the experience of subjective affective states of a positive valence [21,76–79]. 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 include quantification of the time spent in positive affective states.

It is also possible to consider potential non-linearities in the ethical significance of a harm depending on when in an animal's time of life it occurs, with end-of-life experiences generally being of a greater ethical concern than others of similar intensity and duration [80]. These non-linearities may also be incorporated in the estimates, by weighing duration ranges in the Pain-Tracks according to the desired assumptions. Likewise, future knowledge of differences in the intensity of valenced experience across species [72], or in the subjective experience of time across species [81] can be integrated into assessments.

Finally, the integration of all categories of pain intensity into a single 'currency' of welfare loss would be more convenient for practical purposes. Still, we have opted for keeping time in pain of each intensity disaggregated, as evidence to support inferences on the mathematical equivalence between the intensity categories is still lacking (though integration exercises based on theoretical discussions of tentative values can be very insightful [82,83]). Moreover, keeping Cumulative Pain estimates disaggregated, with time in pain expressed for each intensity category, can be more informative, since the pursuit of different priorities, such as relieving the worst kinds of suffering (e.g. time in Disabling and Excruciating pain), becomes possible.

The approach presented here is inspired by simplicity and transparency: the design of a Pain-Track, a framework based on a simple cartesian notation ('intensity vs. time'), is aimed at making its interpretation possible not only to specialists, but also to untrained students and the broad public alike. Its interface is designed to channel existing research and data, along with intellectual effort, where it is needed: in the constant (and ideally cooperative) criticism, update and justification of the values proposed, so animal lives can benefit from decisions based on estimates that are as scientifically sound as possible for their time.

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