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***Abstract*—While essential for survival, seeking and consuming resources might be the source of both damage and stress in dangerous environments, such as environments with predators. While damage can be signaled by pain, pain is also an affective experience not strictly correlated with damage, such as in chronic pain, or when it is modulated by other factors, such as stress. To investigate the complex interplay between stress, pain, and resource seeking, in this paper we investigate the impact of stress on pain perception in the context of survival-related behavior selection in a robot, tested in different environments with varying levels of predation and temporal differences in exposure to predation. Our results show that cortisol-modulated pain perception is advantageous in environments with high levels of stress-related danger, such as predators, and less adaptive in environments with fewer predators and less stress-related danger.**

***Index Terms*—embodied emotions, biologically-inspired robot architecture, pain perception, stress, behavior selection, prey-predator scenarios, autonomous robots**

I. Introduction

The ability to seek and consume resources is critical for the survival and success of both biological and artificial agents, including robots. However, the process of resource-seeking might also be dangerous and the source of both damage and stress in some environments. From the perspective of evolution, one of the key stress factors in such environments is the presence of predators [18], which, in addition to damage and pain, can induce fear and anxiety and affect the agents' ability to perceive and respond to environmental cues. Stress can also impact the agents' perception and experience of pain. In this study, we model such environments using on robots as agents in resource-seeking scenarios presenting similar challenges to those faced by animals in the wild.

In biological systems, pain is a perceptual and affective experience [5] often associated with actual or potential (perceived) tissue damage [6], [21]. In addition to predator damage, the perception of pain is influenced by various factors [15], including the activity level of nociceptors and the concentration of cortisol—the hormone of stress—in the bloodstream [16]. Nociception is the sensory process by which the nervous system detects and processes potentially damaging or noxious stimuli, such as tissue injury or inflammation. Cortisol is a hormone that is produced by the adrenal gland in response to stress. It plays a critical role in the body's stress response system, which is responsible for regulating various physiological processes to help the body cope with stressors [13], [19]. The temporal elements of pain perception [17] can also impact the way agents respond to stressful environments over time. For example, hysteresis—a phenomenon where the response of a system depends not only on its current state but also on its past states—can lead to a delay in the agent's response to changes in the environment. Given the complex interplay between stress, pain, and resource-seeking, it is important to understand how these factors affect agents in different environments with varying levels of predation and temporal differences in exposure to predation. The use of robots to model and experimentally test this interplay in ecologically valid environments contributes, on the one hand, to the understanding of pain in unique ways, by allowing scientists to carry out controlled systematic studies, carefully varying parameters in a way that is not possible with animals in natural environments, and on the other hand, to the broader field of robotics by taking steps towards producing robots better able to perceive and respond to dangers in their environment.

In this article, we investigate the impact of stress on pain perception in the context of behavior selection, where a robot situated in a stressful environment must seek and consume resources timely, and avoid dangers in order to survive. Specifically, we examine how different levels and temporal exposure to predation affect the robot's ability to perceive and "experience" pain, as measured by its lifespan and its management of its internal parameters. By investigating these factors, we aim to provide insights into how agents can optimize their resource-seeking behaviors in stressful environments and improve their chances of survival, as well as on how stress can affect behavior by affecting the perception of pain.

II. Robot Model

The specific robot model and action selection architecture that we have implemented (Fig. 1) are inspired by previous work on homeostatically-controlled motivation-based robot decision making (behavior selection) architectures confronted to a *Two-Resource Problem* (TRP) [3], [11], and the effects of stress on decision making [11], [12], but on this occasion applied to how stress can modulate the perception of pain, and

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how this combination can affect decision making and viability management. In this TRP, a Khepera IV robot [9] needs to maintain its two internal "physiological" variables within a viable range of values that ensures its survival, by seeking and consuming resources available in the environment.

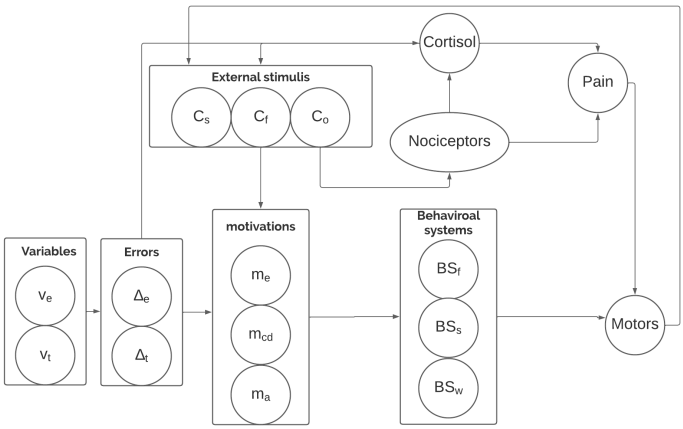

Fig. 1. Our robot's behavior selection architecture.

A. Robot Perception

1) Exteroception: We use the following Khepera IV sensors to detect relevant elements of the environment:

- **Distance Sensors**: objects situated between about 25cm and 1m from the robot are detected using the Ultra Sound (US) sensors located around the body of the robot. For convenience, we'll call them "Distance sensors".
- **Proximity Sensors**: InfraRed (IR) sensors located around the body of the robot are used to detect objects up to 20cm from the robot. For convenience, we'll talk about "Proximity sensors." IR sensors provide values between 1023 (object next to the robot's body) and 0 (object beyond the sensor's range). Proximity sensors are normalized to values in the range 0 to 1.
- **Ambient Light Sensors**: the IR sensors underneath the robot are used to detect the two different types of resources situated on the floor of the arena.

2) Nociception: We conceptualize the robot chassis as an "artificial skin" containing artificial nociceptors [14], [22], which we have simulated using the "proximity" IR sensors, to detect the amount of (simulated) damage that collisions can cause to our robot. Each nociceptor corresponds to an IR, but it provides (is "excited" by) two different signals, corresponding to two different types of stimuli:

1. Impact damage, computed for each IR sensor value (normalized between 0 and 1, where 1 indicates contact with the robot and 0 that nothing is detected) as a function of the speed of approach of obstacles: $impact_i = \frac{sensor_i(t) - sensor_i(t-1)}{(t)-(t-1)}$ if > 0, otherwise $= 0$ (i.e., impact is considered only if the value is positive).
2. Tearing damage, computed using 3 contiguous IR sensors (the left and right neighboring IR sensors of a given sensor). The tearing signal will be stronger the bigger the difference between the pairs of adjacent sensors.

We compute nociceptor values using the mean of both noxious signals: $nociceptor[i] = 0.5 * (impact[i] + tearing[i])$ We induce damage irradiation inspired by the *pain irradiation principle* [1] using a Gaussian that propagates intensity to each nociceptor's neighbors:

1) Generate a 2D array of size $n \times n$, where n is the number of nociceptors
2) for i in range(0, len(self.val)):
3) a) array[i]=self.val
   b) take array[i][i] as center of gaussian and then radiates to neighbors
4) for i in range(0,len(self.val))
5) a) self.val[i] = 0
   b) for j in range(0,len(self.val))
      i) self.val[i] += array[i][j]
   c) self.val[i] = self.val[i]/len(self.val)

B. Motivational system

Following previous work [1]–[3], the robot's decision making is driven by a biologically-inspired motivational system [6] combining a homeostatically-controlled simulated physiology and the perception of relevant external stimuli or environmental cues.

- **Physiological variables** represent the internal state of the body. Each variable represents a vital element that needs to be maintained within permitted values for the robot to remain alive. Variables are noted as v_i .
  - **Ideal value**: Each variable has an ideal value that the robot will try to maintain.
  - **Error**: The mismatch between the actual value of a variable and its ideal value provides an "error" signal, noted as Δ_i .
- **Cues** are perceived external stimuli relevant to the satisfaction of specific internal needs provided by the physiological variables. Cue signals are computed using Ambient Light Sensors, and noted as c_i
- **Drives** are tendencies to trigger behavior that restores physiological balance produced by depletion/deficiency or excess of a substance (eg, water, oxygen).
- **Motivations** are states postulated to explain behavior variability that cannot be accounted by external environmental conditions alone [6]. They are urges to action that combine a drive and the perception of relevant external stimuli. In our architecture, all motivations are constantly assigned an intensity m_i as a function of the error of the physiological variable it is linked with (Δ_i) and of the perception of a relevant external stimulus or "cue" (c_i). To calculate motivational intensity, we use the formula proposed by Avila-Garcia and Cañamero [1], [3], which adapts a classical formula from ethology [20]:
  $m_i = \Delta_i + (\Delta_i * c_i)$

Our robot has three motivations—hunger, cold, and avoid danger. As in [1], [3], following a "Winner-Take-All" strategy,

our action selection architecture tries to satisfy the motivation with the highest intensity at each point in time. A repertoire of behaviors is available to satisfy the different motivations by executing appropriate actions in the environment.

C. Behavioral Systems

Our robot architecture is comprised of the following Behavioral Systems (BS).

- **Seek & Consume** is a complex behavioral system composed of simpler behaviors, both "consummatory" (goal-achieving) and "appetitive" (goal-seeking) [20], organized in "layers". The layers are: consume resources - seek for resources - wander around the environment. The BS will try to execute the "higher" (consummatory) layer first and, if this is not possible, will try the lower ones.
- **Reactive**: a behavioral system that provides the robot with a "danger escape" behavior. It only contains one sub-behavior (implemented using a Braitenberg model) to run away from obstacles.

Each behavioral system is designed to satisfy a motivation, and each sub-behavior has effects on the relevant robot's physiological variables—increasing or decreasing their levels. Each behavior can have a main effect and secondary effects.

D. Cortisol Hormone

In our robot model, a simulated cortisol hormone is used to modulate pain perception [4] based on the robot's physiological state and needs [7]. To compute the concentration of cortisol in the "bloodstream", the robot model uses a formula that considers the robot's comfort level and the nociceptor activity. The release rate of cortisol from an "adrenal gland" [1] is computed using the following equation:

$$r_{cortisol} = \alpha * mean(nociceptors) + \beta * (1 - comfort)$$

where α and β are constants that determine the relative importance of each input parameter. The $mean(nociceptors)$ term represents the average activity level of nociceptors. To compute the robot's comfort level, we use:

$$comfort = mean(1 - \Delta_i)$$

where Δ_i represents the error of each physiological variable, i.e., the difference between its ideal and actual levels (values). The term $mean(1-\Delta_i)$ computes the inverse of the error, and taking the mean across all the physiological variables produces a measure of the robot's comfort level.

The effect of cortisol on the robot is twofold. First, it is used to modulate pain perception based on the robot's comfort level and nociceptor activity [6]. The concentration of cortisol is computed using the formula [1]:

$$c_{cortisol}(t) = max(1.0, c_{cortisol}(t-1) * \psi_{cortisol} + r_{cortisol}$$

where $\psi_{cortisol}$ is the decay constant. By prioritizing resource-seeking behaviors that minimize pain and discomfort, the robot can maintain its physiological variables within the permitted range, which is critical for its survival and efficient operation in the environment. Second, cortisol influences the salience of environmental cues based on the robot's current physiological state and needs. The concentration of cortisol can affect various cognitive and emotional processes, such as attention, memory, and decision-making. By modulating the salience of environmental cues, cortisol impacts the robot's decisions and resource allocation. Our experiments will assess under what circumstances and to what extent this impact can favor (or impair) better decisions.

E. Pain Perception

In humans, pain is a subjective experience that is often associated with tissue damage or the threat of tissue damage. It is an unpleasant sensation that is usually accompanied by an emotional response and can affect various aspects of an individual's behavior, including decision-making, movement, and attention [6], [21]. In our robot model, pain is computed based on the activity level of nociceptors. The concentration of cortisol also plays a role in modulating pain perception, with higher levels of cortisol potentially amplifying the perception of pain. By modulating pain perception, cortisol causes the robot to prioritize resource-seeking behaviors that minimize pain and discomfort while balancing the need to acquire resources efficiently and effectively.

$$pain(t) = c_{cortisol}(t) * damage$$

where $c_{cortisol}(t)$ is the concentration of cortisol at time t and $damage$ is the mean activity level of nociceptors. Changes in the concentration of cortisol modulate the robot's pain perception [10] and can lead to prioritizing resource-seeking behaviors that minimize pain and discomfort [8]. In addition, pain has an impact on the strength of motor action:

$$speed_{(L/R)} = speed_{(L/R)} * (1 + 0.5 * pain(t))$$

When the robot perceives pain, it may reduce the strength of its motor actions to minimize further damage or discomfort. This could affect the efficiency of its resource-seeking behaviors, and the robot must balance the need for resource acquisition with the need to avoid pain and damage.

III. Experiments

We present the results of a series of experiments designed to evaluate the viability and evolution of our robot in an environment with different numbers of predators. We also compare the results of using cortisol to modulate pain perception with those of using only nociception in response to predator attacks. Our hypothesis is that cortisol modulation of pain perception in robots can enhance their ability to adapt to their environment. By modulating the experience of pain associated with predator attacks, robots may be able to more effectively escape or defend against predators, improving their chances of survival.

The primary research question we aim to address in this experiment is: How does cortisol modulation compare to nociception alone in enhancing a robot's survival capabilities in a predator-rich environment? To answer this question, we have designed a protocol to test our robot under different

conditions in a Two-Resource Problem (TRP) environment, where it needs to satisfy the need to consume two resources (food and shade) timely to maintain energy and temperature at a certain level for survival.

A. Experimental setup

Our robot was tested in the context of a Two-Resource Problem (TRP), where it needs to satisfy the need to consume two resources (*food* and *shade*) in order to maintain *energy* and *temperature* at a certain level to stay alive.

The environment (Fig. 2) consists of a $1.5m \times 1.5m$ wooden arena containing two types of resources represented by floor tiles of different textures, which the robot can detect and discriminate between using its IR floor sensors. Resources are symmetrically distributed in this environment.

Fig. 2. Top view of the arena used in our experiments.

We have implemented our architecture using a Khepera-IV robot [9], which is a small, mobile robot designed for research in robotics and artificial intelligence. It has a circular shape and is 5.5 cm in height and 10 cm in diameter. The robot is equipped with a range of sensors, including the ones we described in Section II-A1.

We have used Thymio-II robots (www.thymio.org) to implement predators. We have endowed predators with various behaviors such as static, aggressive, or prey-searching. For the purpose of studying the impact of stress, we have specifically implemented a "stalking" behavior. In this behavior, the Thymio-II robots move slowly, avoid the environmental border, and when they detect an object or another robot with their proximity sensors, they attempt to follow and attack it. It is important to note that when the Thymio-II robot makes contact with the Khepera-IV robot, it continues its stalking behavior, posing a persistent threat to the Khepera-IV robot. The predators implemented allow us to create a controlled and reproducible predator environment and investigate how different levels of predation affect the perception of pain and resource-seeking behaviors and survival of the Khepera-IV.

B. Experimental protocol

To investigate how different levels of predation impact the perception of pain and resource-seeking behaviors and survival of our robot, we study how stress (cortisol) impacts the robot behavior and impacts the management (viability) of its physiology. We also study the temporal dynamics of our model using different models of computation for hormonal concentration based on hysteresis or direct memory. Thus, we set up the following protocol. For each run:

- The robot is placed on the center of the bottom border of the arena, facing the upper border.
- If the run contains predators, they are placed symmetrically on the arena following the schema shown in Fig. 3.
- The run starts as the robot starts moving.
- The run is stopped after 600s, or sooner if the robot dies before the end of the run.

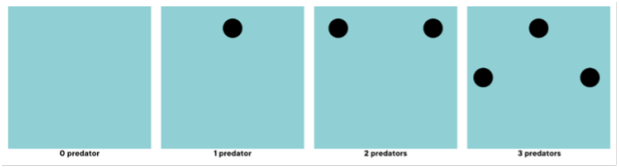

Fig. 3. Positions of predators in the arena for 0, 1, 2 and 3 predators.

As we wanted to study the impact of cortisol on our robot in different stress-related environments, we tested it in the eight following experimental conditions, in which we varied the number of predators present in the environment (between 0 and 3), and the relation between damage and pain, as follows:

- A linear correlation between damage and pain
- A cortisol-modulated computation of pain

ID	Number of 'stalking' predators	Resources position	Pain perception stimuli	Hormonal concentration
N1	0	Symetrical	Nociceptors	Memory
N2	1	Symetrical	Nociceptors	Memory
N3	2	Symetrical	Nociceptors	Memory
N4	3	Symetrical	Nociceptors	Memory
C1	0	Symetrical	Cortisol	Memory
C2	1	Symetrical	Cortisol	Memory
C3	2	Symetrical	Cortisol	Memory
C4	3	Symetrical	Cortisol	Memory

Fig. 4. Experimental conditions. Scenarios named 'N' denote those with a linear correlation between damage and pain, those named 'C' indicate a cortisol-modulated computation of pain.

We run the robot 5 times in each of the 8 conditions, with a total of 40 runs. This decision was based on a combination of practical considerations and statistical considerations, aiming to achieve a balance between obtaining meaningful results and efficiently utilizing available resources. The number of runs allowed us to capture the variability in the system's behavior and assess the robustness of our findings. Furthermore, replicating each scenario five times helped mitigate potential sources of variability and provided a more comprehensive understanding of the model's performance.

C. Results

We measured the performance of the model using the following different metrics.

1) Survival of the robot: We recorded the survival of the robots in the 5 runs of 600s (or shorter if the robot died early) that were performed in each condition. Survival rates can be seen in Fig. 5, which shows that the cortisol-modulated robots had higher survival rates than the damage-correlated ones. In low-level of predation danger conditions, while N2 has only 80% survival rate, the robot survived in 100% of the runs for N1, C1 and C2. In environments with higher level of predation danger (C3, C4, N3 and N4) we can observe that, even if survival rate lower to 80% for cortisol-modulated model, it lowers to 60% and 30% when there are 2 and 3 predators for the damage correlated model.

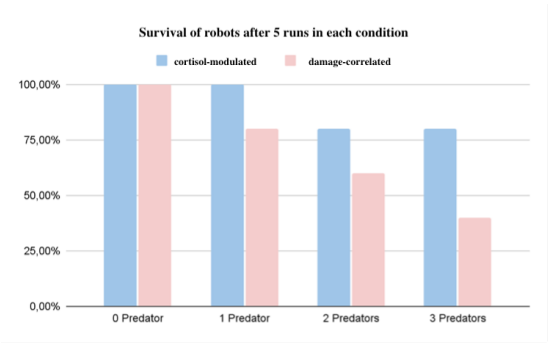

Fig. 5. Survival rate of the robots after 5 runs of 600s in each condition.

In the damage-correlated model, the robots had more difficulties dealing with repeated attacks of predators, which led to underconsumption of resources and subsequently to the death of the robot. This trend increased with the number of predators. In the cortisol-modulated conditions, where the level of cortisol acts as a memory of previous stressful experiences, the robots were better able to avoid the predators and survive.

2) Activity cycles: We examined the activity cycles [1], [3] of our "cortisol-modulated" and "damage-correlated" action selection robot models, each of them under four different experimental conditions (C1 to C4 and N1 to N4, respectively) to evaluate their performance in maintaining the viability of the two physiological variables. When plotting the temporal evolution of the physiological variables in the physiological space, the repeated execution of sequences of behaviors can give rise to cycles, called "activity cycles" in the ethology literature. Such cycles show the management of the physiological variables in the range of permissible values, and with respect to each other.

As we can see in Fig. 6, in the cortisol-modulated action selection architecture, across all conditions the activity cycles did not exhibit any signs of lack of balance in resource consumption, i.e., of underconsumption of one resource in profit of the other one. Instead, the robot demonstrated a fair and balanced seek-and-consume behavior, effectively maintaining its physiological variables within the permissible ranges.

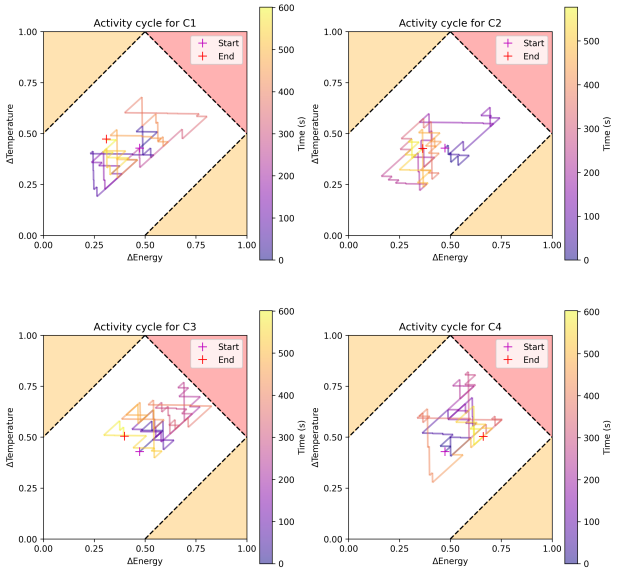

Fig. 6. Activity cycle for the cortisol-modulated model in C1, C2, C3, C4. $\Delta_{Temperature}$ is compared to Δ_{Energy}. The yellow and red areas correspond to "danger zones" (with high deficits for one or both variables, respectively) in the physiological space.

By comparison, the activity cycles of the damage-related model, shown in Fig. 7, show poorer viability management. In particular, in all conditions (N1 to N4), the deficits at the end of the run are higher than at the start, the balance between the variables is less good in N1, and the deficits higher and close to (and into) the "danger zone" in N1, N2 and N4.

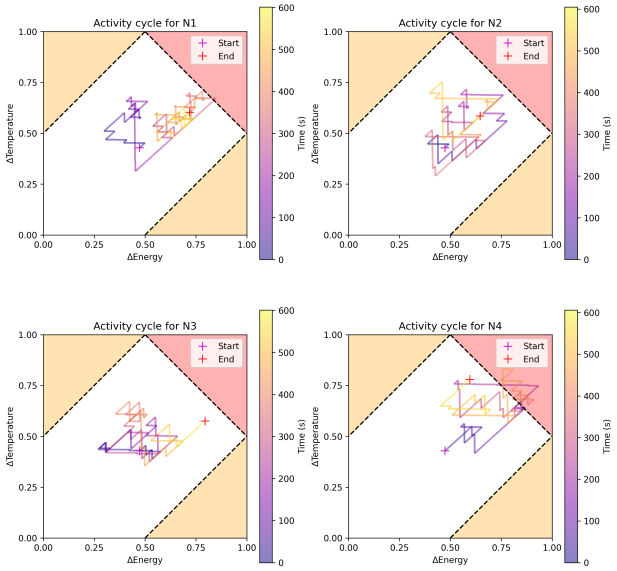

Fig. 7. Activity cycles for the damage-correlated model in N1, N2, N3, N4, $\Delta_{Temperature}$ is compared to Δ_{Energy}The yellow and red areas correspond to "danger zones" (with high deficits for one or both variables, respectively) in the physiological space.

According to the activity cycles, our results show that with cortisol modulation of pain perception, our robot can deal

more efficiently with dangerous environments and prioritize resource acquisition in a contextually appropriate manner.

3) Intensity of cortisol over time: We analyzed the relationship between cortisol levels and the number of stalking predators across the three conditions with predators (C2 to C4). As we can observe in Fig. 8, our findings show a notable correlation between the intensity of cortisol over time and the presence of predators in the environment. In conditions with fewer predators (C1, C2), the robot exhibited lower cortisol levels, indicating reduced pain perception and stress. Conversely, in scenarios with a higher number of predators (C3 and C4), cortisol levels were maintained at a high level for extended periods, due to the "hysteresis" of hormonal concentration resulting from the interplay of release rate and memory.

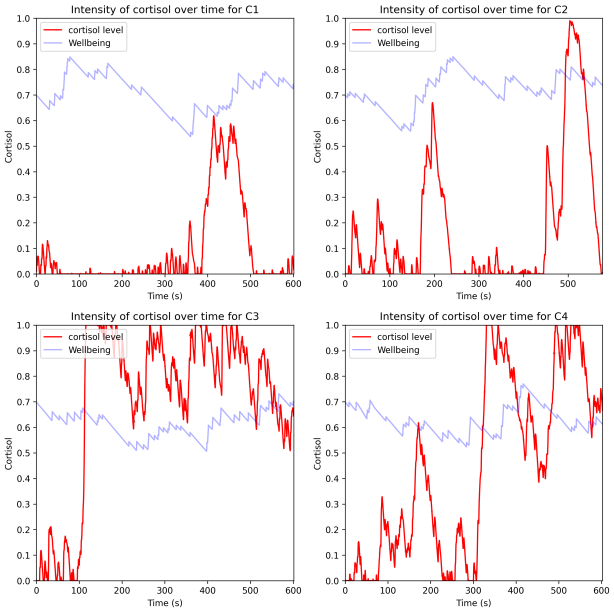

Fig. 8. Intensity of Cortisol and wellbeing (the inverse of the mean of the error of the physiological variables) over time in C1,C2,C3,C4.

This observation highlights the influence of prior stressful encounters on the robot's behavior in subsequent situations. The persistent increase of cortisol levels in the high-predator conditions illustrates the robot's capacity to "remember" and adapt its behavior based on past events. By modulating pain perception and stress response, the robot can effectively respond to specific environmental challenges, demonstrating the value of incorporating biologically-inspired mechanisms in robotic decision-making architectures for enhanced adaptability and contextually appropriate performance.

4) Hormone Secretion Dynamics Graph: Our analysis of the hormone secretion dynamics graph (Fig. 9) shows distinct clustering patterns for each scenario (C1 to C4), providing valuable insights into the interplay between cortisol concentration and release rate in the context of varying predator presence. To determine the number of clusters for each scenario, we used elbow method and x-mean. In condition C4, the distribution appears uniform, while in C3, we observe two clusters: one with high cortisol concentration and low release rate, indicative of memory's impact on hormonal concentration, and another with both low concentration and release rate, as well as a region where concentration is low and release rate is high. For condition C2, two clusters emerge, with a smaller one exhibiting high concentration and low release rate, and a larger one characterized by low concentration and high release rate. This pattern suggests that cortisol exhibits lower memory dynamics when fewer predators are present, a trend that is further confirmed by the clustering observed in condition C1, where only the cluster with concentration and high release rate.

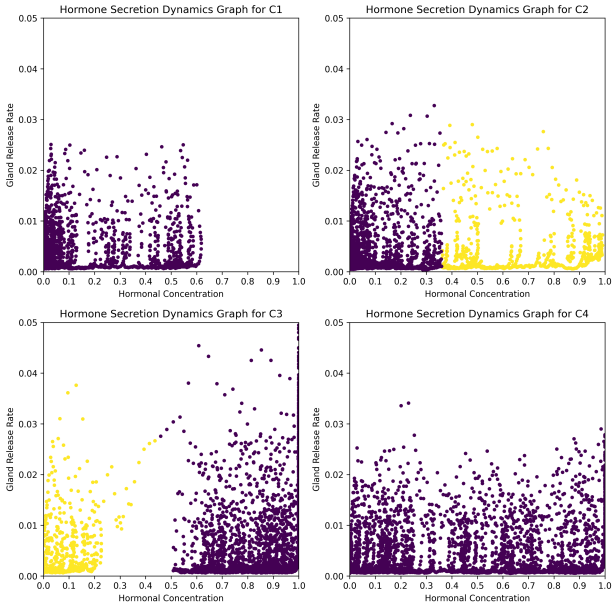

Fig. 9. Hormone secretion dynamics graphs for C1,C2,C3,C4. Hormonal concentration is compared to gland release rate to understand the hormone evolution in specific scenarios

These findings emphasize the role of cortisol in modulating the robot's perception of pain and stress response, with varying memory dynamics based on the number of predators in the environment. By adapting its hormonal regulation in response to environmental challenges, the robot is able to demonstrate enhanced performance and adaptability.

5) Intensity of Motivations Over Time and Nociception—The Example of C3: In our experiments, we explored the interplay between nociception and the selection of motivations in our cortisol-modulated robot model. Taking scenario C3 as an example, where the robot faces two predators in the arena, we observed in Fig. 10 and Fig. 11 a strong correlation between nociceptor activation and the choice of motivations. In these figures, we can see a significant increase in nociceptor excitation around the 110-second mark. During this phase, the robot consistently selects the danger motivation for an extended period. The elevated nociceptor activity corresponds to the emergence of an attack behavior, wherein the robot confronts and engages with predators while simultaneously

activating some of its nociceptors. Interestingly, when multiple nociceptors are excited, the robot prioritizes the danger motivation over the other motivations—hunger and cold. This finding highlights the adaptability of our robot model to varying environmental conditions and threats.

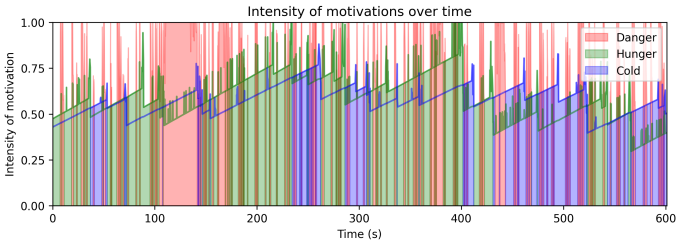

Fig. 10. Intensity of motivations over time for C3.

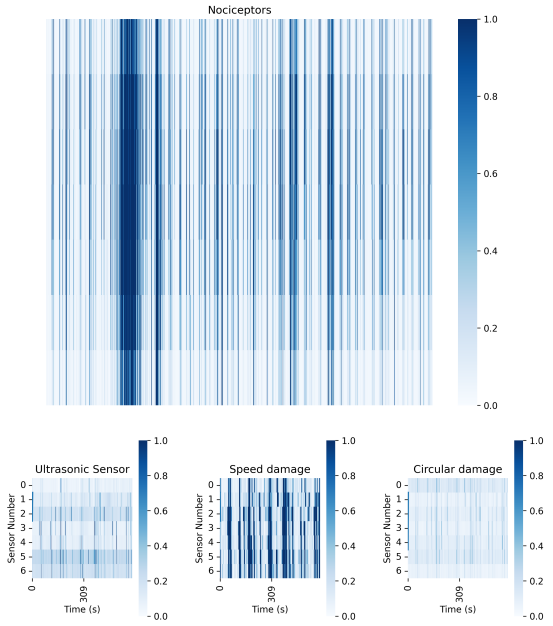

Fig. 11. Nociceptors, sensors and damage Heatmaps for C3.

6) Emerging Behaviors: We have observed an intriguing behavior in our cortisol-modulated robot model when confronted with multiple predators. Specifically, in scenarios C3 and C4, where the number of stalking predators is higher, the robot appears to engage in a "fight" response, characterized by executing left and right turning loops and occasionally making contact with the predators, repelling them. This behavior is more prominent when cortisol levels are elevated. The integration of cortisol in the action selection architecture serves to modulate the robot's perception of pain, analogous to the stress response in biological organisms. As cortisol levels increase, the robot's aversion to pain diminishes, allowing it to engage in riskier behaviors. In Fig. 12 we can observe an example of this behavior during scenario C4. In this particular moment, the robot is chased by 2 predators and the third one is coming in its direction. The Khepera robot is blocked and will make a contact that will repulse one of the three predators, allowing it to escape the first attack of the two predators.

Fig. 12. Emerging attack behavior in C4 : (A) the robot is confronted to two predators blocking a resource. (B) the robots turn in the direction of the predators. (C) The robot repulses one of the predators, accessing the resource. (D) The robot turns to escape.

This may be interpreted as an adaptive strategy to cope with the high-threat environment, wherein the robot prioritizes self-preservation and resource acquisition by actively confronting predators rather than solely avoiding them.

IV. Conclusion

In this paper we investigated the impact of cortisol-modulated pain perception on the behavior of a robot confronted to a behavior selection task in environments with different levels and temporal dynamics of predation. We conducted a set of experiments to understand how cortisol can impact the viability of the robot in a two–resource problem. We observed that cortisol, when introduced into the robot model, provides adaptive benefits under different levels of predation-induced stress and danger with an increasing number of predators in a limited area. We observed the adaptive value of cortisol-modulated pain perception in term of survival rate by the end of experiment, in term of maintaining a balanced deficit of physiological resources in the context of a two-resource problem. We then studied mechanisms related to this model to understand how the model reacts to predation stimulation and how it adapted in this context. These benefits manifest as the emergence of contextually appropriate behaviors and the ability to maintain balanced seek-and-consume patterns in response to environmental challenges. Cortisol, and therefore stress, seems to be an important feature for the perception of a pain in the Motivation-Emotion-Cognition Loop. In further work we'll study different temporal dynamics with the computation of the hormonal concentration or with pain perception in order to study how long-term sensitization can impact our pain perception and leads to chronic pain. We could change the memory decay or use another non temporal method to compute pain perception.

Acknowledgment

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Ethical Impact Statement

In this study, we focused on the effects of stress and predation on pain perception in robots to get a better understanding of the pain mechanisms in humans.

Collaboration with Psychologist: To ensure the relevance of our work, we discussed with a clinical psychologist specialized in human pain. This collaboration allowed us to design our experiments with a better grounded understanding of human pain mechanisms and to potential impacts.

Working with Models: In our research, we have not directly worked with human data. We used robot models to investigate the complex interplay between stress, pain, and behavior selection. By focusing on robotic models, we minimize any potential harm to human subjects while still trying to develop findings that could be applicable and useful in a human context.

Future Generalization: We hope that the insights gained from this study will contribute to a better understanding of pain perception and its modulation by stress factors, which could eventually be applied to real-world contexts and benefits to pain studies.

Environmental impact: We recognize the environmental impact robotic research can have. To limit energy consumption and data computation, we have limited the number of experiments to the minimum necessary to obtain reliable data. We have also focused on utilizing low-cost methods for computation in the robot model.

Our study has been designed with ethical considerations in mind. We have collaborated with psychologist, utilized robot models and no human data, and limited our experimentation to the minimum necessary to limit our environmental impact. Our goal is to contribute to a better understanding of pain perception and its relationship with stress, which could ultimately give a better understanding of pain.

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