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Review

Insight in perception of pain in sports – selected aspects

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Purpose: Research in recent decades has shed light on the neurophysiological mechanisms of pain, which not only has an information and warning function, but is also considered an important diagnostic factor. The results of various studies indicate that physical activity, especially at moderate intensity, modulates the intensity of perceived pain and generally leads to its reduction.The aim of this study was to characterize in depth the effects of physical activity on pain perception, in particular to deepen the knowledge of the direct and indirect effects of recurrent repetitive injuries on pain perception and modulation of the activity of the endogenous antinociceptive system.
Methods: This article reviews the current state of knowledge on the effects of physical activity and injury on pain perception and the role of the endogenous analgesic system in pain modulation.
***Results*:** Both excessive physical effort and a lack of physical activity are factors that increase the risk of pain. Physical activity, especially training in athletes, exerts loads on the locomotor system structures and by means of the nociceptive system signalises potential hazards through pain. At the same time, these very same loads trigger the processes activating the endogenous analgesia systems. In the case of intense and prolonged physical activity, these systems are subject to adaptation as well as exhaustion.
Conclusions: For athletes and amateur athletes, knowledge about pain has a practical dimension, enabling conscious, knowledge-based monitoring of applied loads and control of the body's condition. Gaining knowledge about pain in sports can be of great practical importance in the in the training process, during the competition but above all the prevention of injuries. The intensity and quality of pain, although these are subjective feelings, can be defined and analyzed in clinical practice and in research conducted on physically active people, using established procedures and appropriate tests.

Keywords: pain, physical effort, sport, injuries, measurement of pain.

Introduction

The last three decades of research have shed light on the neurophysiological mechanisms responsible for peripheral reception of sensory stimuli and their processing in the central nervous system. In this context, it is particularly important to understand the structure and function of the nociceptive system and pain that is experienced as a result of its activation. The importance of the subject discussed is evidenced by nearly 70 000 publications recorded annually in the recent years, available in the PubMed database when searching for the term "pain" (Fig.1) The knowledge acquired to date allows for precisely describing the neurophysiological processes beginning with transduction, i.e. the harmful (nociceptive) stimulus affecting the tissue, creating of local inflammation, through the conduction of the signal using peripheral pathways, to the generation of the sensory phenomenon known as pain in the brain structures. It is also known that the perception of pain is to a large degree modulated by the circumstances in which it occurs. These include a broad spectrum of factors, especially of environmental, social, but also emotional or religious nature. Therefore, the perception of pain can be strengthened or weakened depending on the motivation, activity or pain management strategy of a given person. This subjective aspect differentiates nociception from pain and allows for the modulation of the latter.

Physiologically, pain has an informative and warning function, as it signalises direct or potential tissue damage. It also serves as a protective mechanism by significantly increasing the chances of human survival. Furthermore, it allows for learning about the environment and avoiding situations that may be hazardous to one's health or life. In the clinical aspect, pain serves a diagnostic function, indicating the site of an injury and ongoing pathological processes, as well as a monitoring function, as increasing or decreasing pain allows for the evaluation of a given condition. Pain or lack thereof is also a subjective criterion of disease or good health, respectively. It is also worth mentioning that pain evokes negative and unpleasant emotions and feelings as opposed to other sensory phenomena such as taste, smell or touch, which can be perceived both positively and negatively.[1]
The negative emotional attitude towards pain, expressed especially through the inborn flight response and self-protective behaviour, is present at every stage of life. Physiological, neuropsychological, hormonal and behavioural reactions to pain and non-pain stimuli were described as early as foetal life.[2] Over the course of human ontogeny, the occurrence of pain increases

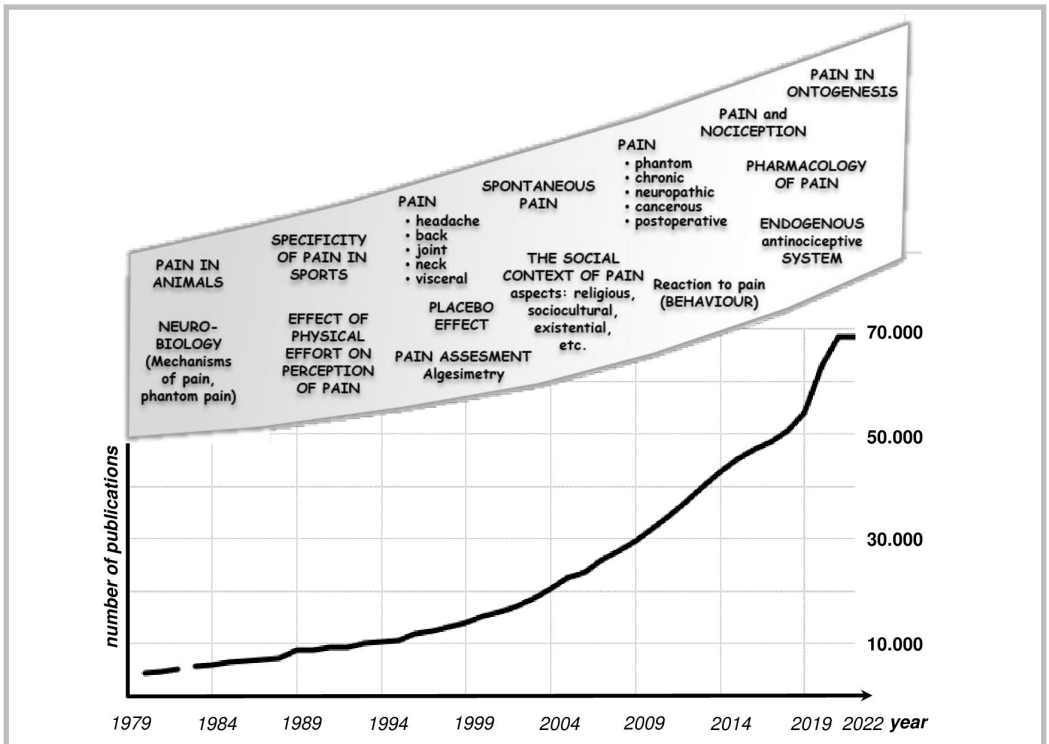

Figure 1. *PubMed database search results for the term "pain" over the period of three previous decades. Research areas and problems closely related to the subject of pain are listed above the figure.*

considerably, as indicated by the fact that on average 30% of people aged 25-50 reported about headaches at least once per month, over 50% felt musculoskeletal pain occurring at least once per year, while 80% of women indicated menstruation as the cause of pain.[3]

Pain is a sensory phenomenon that is highly individualised, as it involves the physical, cognitive and emotional spheres of human life. Pain does not have to be a response to tissue damage, but according to its definition, it can also manifest "in relation to potential tissue damage or sensations which may be described using terms referring to such damage".[4] By contrast, nociception includes objective neuronal processes that occur with the involvement of the nociceptive system, which allow for the reception of noxious stimuli, signal transmission to the central nervous system (CNS) and central processing of nociceptive information (Fig. 2).

Pain is a complex phenomenon. In addition to its most characteristic sensory-discriminative aspect that allows for locating the stimulus and evaluating its intensity, pain also has emotional (affective), locomotor and autonomic (vegetative) aspects. The broad spectrum of methods used to treat pain also confirms its complex nature. Apart from pharmaceuticals, pain can be treated using physiotherapy and psychological methods involving relaxation techniques, meditation, hypnosis or biofeedback. This indicates that the study of pain is not limited to the domain of medical and biological sciences, but also lies within the domain of humanities, especially psychology and sociology. For ages pain has also inspired artists and philosophers, indicating that the boundaries and relations between the stimulus, pain and suffering are not clear cut.[1]

The aim of this publication is to present our perspective, based on the current literature, the existing state of knowledge on the specificity of pain especially in athletes and physically active people. The authors discuss direct and indirect consequences of injury and training loads on pain perception and describe the immense modulatory potential of endogenous analgesic mechanisms and the placebo effect in sport.

Injuries in sport

Increased loads and high number of training sessions completed by athletes and physically active individuals result in an increasing number of microtraumas, damage or injuries categorised as strains, tears, bruising, sprains, dislocations or fractures. Various types of injuries pose a risk for athletes. Most often they occur as a result of several coexisting factors dependent on athletes themselves, environmental conditions as well as the characteristics of a specific discipline.[5] This seems particularly relevant in the case of adolescents, who make an early choice of the discipline to which they are going to devote an increased amount of time. Consequently, the discipline-oriented exercises and training sessions result in greater stress exerted on particular structures of the locomotor system, leading to an increased risk of injury among members of this age group.[6,7] All injuries manifest with pain, which is a subjective sensory experience, providing information about the actual or potential tissue damage. Interestingly, typing the keywords pain and sports into specialized, medical databases recently brought up nearly 4,000 publications per year, but accounted for only 4-6 percent of scientific papers on pain. The above may confirm a different/specific way of valuing and subjectively perceiving pain in athletes.[8]

The accumulation of injuries is particularly dangerous, as it may lead to premature wear of some structures, especially joints, chronic pathological processes in the locomotor system, exacerbation of symptoms, and progression of the dysfunction.[9] The risk of injury increases especially in the case of ignoring the current knowledge and attempting to find shortcuts to success in sport without taking into consideration the actual capacity of the locomotor system and the maturation stage of the nervous system in both young athletes and older sport amateurs. Furthermore, during the recovery process high-quality specialised tissue is replaced with lower quality tissue. In the case of multiple, repeated micro-traumas, this leads to the loss of specific properties of the tissue, especially its flexibility, limiting the scope of motion or causing the loss of fitness.[10] From the

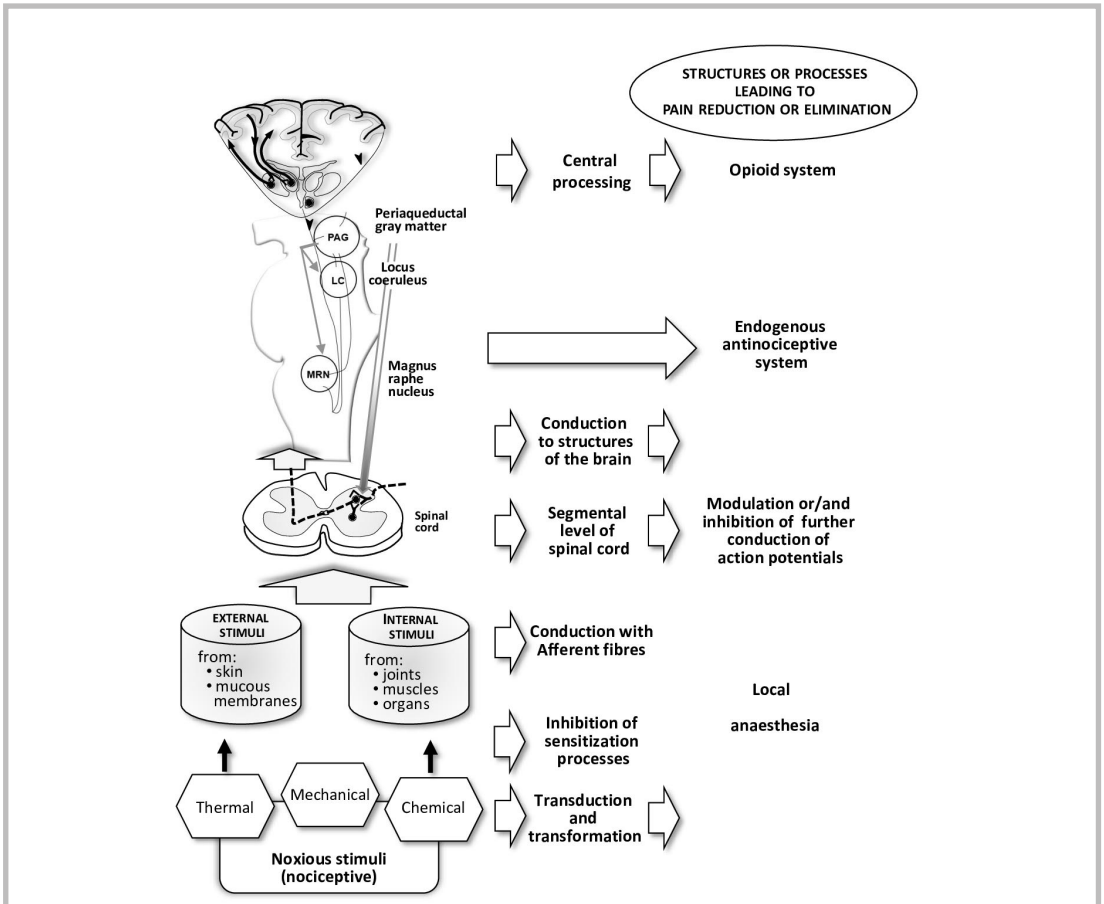

Figure 2. *Neuronal processes occurring in the nociceptive system resulting in the subjective perception of pain, starting from the noxious (nociceptive) stimulus affecting the tissue, through its afferent transmission, to its processing in the central nervous system. Neurons in the dorsal horns of the spinal cord not only receive signals from the afferent nerve fibres directly but are also connected to a large number of excitatory and inhibitory interneurons, which modulate their excitation level through presynaptic and postsynaptic connections. These interneurons are also the target of various segmental and supraspinal connections, whose complex nature has not yet been fully understood.*

physiological perspective, in all of these cases nociceptors receiving noxious stimuli are activated and directly or indirectly trigger inflammation in the tissue.

There are many ways of decreasing physical discomfort and modulating pain sensation in athletes and physically active individuals. These include physiotherapy, individual or group motivational sessions and the use of analgesics. The antinociceptive system, an endogenous tonic acting system that is enhanced and modulated by injuries and other pain predisposing factors, plays a crucial role in reducing the perception of pain.

Endogenous analgesic effect

One of the elements limiting high performance in sports, or at the very least repeating one's previous athletic achievements, is pain associated with the experienced fatigue or injuries. Apart from its most important, already mentioned function of warning about danger posed to tissues by noxious stimuli, the nociceptive system can participate in modulating or even inhibiting the transmission of such information to the nociceptive structures of the CNS. As a result, the excitability of second-order sensory neurons located in the spinal cord and receiving the afferent nociceptive signal may be decreased. This is because at the segmental level there are both local processes involving the inhibition of nociceptive information incoming from the peripheral nervous system, usually through the activity of inhibitory interneurons releasing neurotransmitters, glycine and GABA, as well as tonic inhibitory processes through the descending pathways of the nociceptive system, modulating the activity of ascending second-order neurons.

Consequently, the threshold of these cells is increased which, in turn, decreases the probability of their response to the incoming noxious stimuli. This tonic effect, i.e. the constant descending inhibition, together with the aforementioned segmental inhibitory interneurons, forms an endogenous antinociceptive system, which controls the pain through negative feedback.[1]

The descending toning inhibition starts at the nervous structures located in the brain stem: periaqueductal grey (PAG), locus coeruleus and raphe nuclei (Fig. 2). It may be assumed that the weakening or damage of these inhibiting descending pathways facilitates central sensitisation or even the self-reliance of the central nociceptive mechanisms predisposing for chronic pain. In this case, the function of neuromodulators in the descending antinociceptive system is performed by endogenous opioids. Their presence and ability to bind to opioid receptors leads to the inhibition of the neuronal nociceptive activity at the segmental level of the spinal cord, which mostly involves reduced release of excitatory transmitters (presynaptic inhibition) or hyperpolarisation of cell membranes in postsynaptic neurons (postsynaptic inhibition).

The opioid system receptors activated by endogenous ligands are also affected by a number of other agonistic or antagonistic substances, which are found in plants or synthesised for pharmacological purposes. What is also worth mentioning is placebo, which seems to be an interesting aspect of pain modulation is sport. Placebo can be effective in this respect, as it

activates the same brain structures as opioids[11] and its analgesic effect often exceeds 50%. This may directly or indirectly result is supporting, maintaining or improving athletic results by reducing the pressure to achieve them and mitigating the nuisance of stressors, including injuries or pain.

Studies have shown that evaluating the placebo effect in athletes is much more complex than in the case of patients or volunteers. When athletes were informed and convinced about the effectiveness of certain substances or methods, e.g. application of anabolic steroids[12], supplementation with caffeine[13], supplementation with a hypothetical "wonder supplement"[14] or performed training using a respiratory device[15], they improved their performance as compared to the reference group or control group. It was also demonstrated that athletes intending to use supplements are more susceptible to placebo.[16] Furthermore, it was found that when athletes were switched to placebo after receiving several doses of opioids in the pre-peak period of training, they still felt the same positive effects expressed as elevated pain threshold and maintained high physical performance.[17] The above demonstrates the potential of endogenous analgesic mechanisms as well as the effectiveness of placebo in sports.

Pain during physical activity in sport

As mentioned before, pain is a subjective sensation. This means that the same stimulus will be perceived differently by different individuals, i.e. as more or less intense or as a smaller or greater discomfort. One of the factors that modulate the perception of pain is physical activity.

In sport, pain usually has a specific cause and predictable duration. There are also well-established methods that lead to its reduction or complete elimination. It is an integral part of sporting experience, as it indicates the limits of loads that the body can handle.[18] Athletes often perceive pain, especially muscle pain following a bout of physical activity or a training session, as a positive sign suggesting, sometimes incorrectly, that the training was conducted well and with good intensity.

Pain tolerance in athletes seems to vary depending on their discipline, with differences observed between individual and team sports as well as between contact and non-contact disciplines.[19]. The importance of individual differences in the subjective tolerance of pain has been demonstrated in a study by Raudenbusha et al.[20], who found that pain tolerance increased in people actively playing video games or watching sport videos, especially martial arts videos. Due to regular exposure to short intense pain events during training and in competition, martial artists have to be better at handling pain than athletes practicing other disciplines. Practical observations indicate that pain occurs relatively often in athletes.,[19,21,] Therefore, it may be assumed that the awareness of the inevitability of pain is not only an integral part of training, but also forces the athlete to develop the need and skills to develop pain management strategies.

Findings from various research studies indicate that even relatively low physical activity can modulate the perceived threshold of painful and non-painful stimuli.[22,] This is also corroborated in the conclusions of the meta-analysis conducted by Tesarz et al.[23], who observed higher pain tolerance in athletes as compared to the control group comprising non-training individuals and demonstrated that regular physical activity is related to changes in the perception of pain. This effect, known as "acute exercise-induced hypoalgesia", lasts for a limited and variable time, usually shorter than 30 minutes, after a single bout of exercise.[24] Furthermore, physical activity predisposes athletes to the occurrence of other physiological mechanisms.[23,25] However, the resultant pain may also be determined by other factors, such as psychological and environmental ones, which may individually or jointly affect the athlete.[26] Nevertheless, it is not completely clear whether the uninterrupted, repeated, often prolonged (sometimes lasting for years) inflow of pain stimuli and loads combined with an intense use of the defensive endogenous systems is neutral for athletes or whether it causes short-term or long-term adaptations (and if so, what these adaptations are). The multitude of stimuli and research techniques used in various studies is not conducive to a univocal evaluation of the results published in this field, especially when comparing athletes of different sex, practicing different disciplines, and including the results of animal testing. This lack of homogeneity has been pointed out on several occasions over the last few years.[23,27]

As mentioned before, the endogenous analgesia system plays a critical role in inhibiting the sensation of pain. The system is also active in high-stress situations, also an oversized effort, in which case it releases glucocorticoids, catecholamines, as well as endogenous opioids (Fig. 2). It was found that athletes practicing some disciplines, especially martial arts and contact disciplines e.g. team games, had a significantly higher pain threshold in response to a cold stimulus, higher tolerance to painful cold and mechanical stimuli as compared to members of the non-training group.[28] In a study by Tesarz et al.[23], pain tolerance in athletes was comparable to the effect of strong opioid substances used in acute pain. It is also interesting to note that athletes practicing team ball sports had the highest pain tolerance, exceeding the values found in athletes practicing endurance and strength sports.[23]

A more qualitative and in-depth insight into the subject of pain in sport has been possible due to the use of the quantitative sensory testing protocol – QST. [29,30] This technique was developed for the purpose of clinical studies involving patients and is based on the resultant of several threshold measurement for different stimuli including temperature (heat and cold), vibration, absolute threshold and pressure. Studies using this method demonstrated that some of the defined stimuli resulted in a lower activity of the endogenous pain modulation system in athletes as compared to non-training individuals.[30,31] This would suggest possible changes in the baseline activity of the endogenous pain inhibiting system resulting from intense training and allow to adopt a hypothesis stating that, in general, the endogenous system in athletes requires stronger stimuli to become activated as compared to non-training individuals[32], because after an extended period time, intense physical activity causes a "deficit" in the endogenous pain inhibiting system.[30] If such is the case, it should be assumed that an optimum level of physical activity is conducive to low prevalence of pain, while very little as well as very intense physical activity results in its increased prevalence. Research conducted on larger groups indicated that both insufficient and excessive loads resulting from physical work equally predispose to the occurrence of pain.[33] To date, the population variability and individual profiles of indicators characterising the antinociceptive response of the endogenous opioid system in males and females remain unknown, especially in relation to physical effort. However, based on the data available, it is possible to speculate that at least among a certain group of individuals long-term intense training can lead to the reduction of their adaptive capacity or other kinds of exhaustion of the endogenous pain inhibiting system. This would explain why pain syndrome and generalised pain are also found among athletes. This concept is also consistent with the observations of decreased activity in PAG, an important structure responsible

for descending inhibition, caused by exercise load. Using fMRT imaging methods, it has been demonstrated that intense physical work leads to severe decrease in PAG activity, while moderate physical activity, e.g. a walk, causes the opposite effect, resulting in increased PAG activity.[34] Sluka et al.[27] discussed another aspect of the problem, i.e. the activation of the immune system through physical activity and the possible imbalance between pro- and anti-inflammatory cytokines in the context of activation or sensitisation of nociceptors.

A separate factor, not addressed in numerous studies, is the overall condition of the nervous system, the degree to which it is affected by metabolic or environmental diseases. Other "classic" factors such as age or sex are also important. Epidemiological studies indicate that women are at an increased risk of developing chronic pain and may suffer from more severe pain when affected by a disease.[35] The incidence of chronic pain also differs between men and women, regardless of their physical activity level.[36] The perception of pain also changes during ontogeny. It is known that the prevalence of chronic pain in relation to acute pain[37,38] increases with the age of the population, which is most likely the direct or indirect consequence of the structural and functional aging changes, especially in the nervous system.[39] Electrophysiological testing on laboratory animals confirms that the reaction to pain is more severe in older individuals.[40]

In specific situations, pain can also be a destructive factor, triggering or enhancing the nocebo effect. Deroche et al.[26] indicated that the exaggeration of pain by athletes led them to avoid it by withdrawing from *games* or training sessions or at least by avoiding high risk situations during games. Healthy individuals who were not very active and who exaggerated their muscle pain also significantly reduced their physical activity, even after the pain intensity had been verified.[41]

Measurement of pain in physically active people

In the case of pain, the question arises of what measurement methods and which units should be used to assess the strength, intensity or annoyance of pain in a situation where there is no such thing as a pain unit, and pain itself is defined as a subjective feeling. Pain measurement, i.e. algesimetry, is extremely significant in clinical management, because the reduction of pain in the patient plays a diagnostic role, indicating the correctness of the selected therapy. Clinical pain is more difficult to measure, due to its unpredictability and strong emotional component.

In the case of measuring pain in healthy people, especially those active in sports, the situation is more comfortable and more predictable for both parties, the volunteer, who subjectively determines the strength of the impact of an objective and defined stimulus, and the researcher, who can compare old and new results from the same person and describe the area in which they fall.

Due to the multifaceted nature of the sensory phenomenon that is pain, it is difficult to build an instrumentarium suitable for describing this problem. The ideal tool in the assessment of pain should include the identification of the presence of pain, as well as the progress of pain with time or treatment in the case of experimental studies conducted on volunteers, including athletes, measurements are most often carried out using calibrated devices or special tests. Although these measurements are still subjective, the subject formulates and translates the subjectively felt pain into a specific value in the pain scale adopted for all participants, starting with a zero value (no pain) and a maximum value (unbearable pain). In addition, high-threshold stimuli administered to volunteers are repeatable and measurable.[42]

Mechanical and thermal stimuli are most commonly used to assess pain. Occasionally, an electric current or laser is used. When using a mechanical stimulus, an algometer is used, i.e. a device that scales the pressure of the applied pain. The algometer is used to quantify and document pain sensation by measuring **pressure pain threshold** (PPT) and pain sensitivity using **pressure pain tolerance measurement** (PTOL). Pressure algometry is a reliable measure of pain in muscles, fascia, joints, tendons, ligaments and periosteum. Measurement of tissue pressure sensitivity can be performed using various types of algometers. The principle of operation is simple: the researcher places the head at the point to be examined and presses on the tissue with increasing speed (kPa/s, kg/cm^2). The result is displayed in the main window or can be saved in the corresponding file.

Using algometer both, pain threshold (PPT) and pressure pain tolerance (PTOL) can be defined. PPT is understood as the minimum amount of pressure required for the sensation of pressure to first change to pain, while PTOL describes the maximum stimulus intensity or duration of continuous painful stimulation that a person is willing to endure.

The **cold pressor test** is a standard laboratory procedure for measuring pain and pain tolerance thresholds: in each test, the subject immerses his right hand up to the wrist in a basin of water maintained at 37 °C by a pump. The hand remains in the warm water for 2 minutes to normalize skin temperature.

The participant then places the hand in a container filled with an ice-cold water mixture avoiding contact with the walls and bottom of the container. The temperature monitored by a build-in thermometer should be kept between (0–0.5 °C). The hand of person tested remains in the ice water until the participant can no longer tolerate the pain.[43]

The participant indicates "pain", when he feels the first pain sensation in the hand, then we define the pain threshold (PPT), when it becomes unbearable, we mark the pain tolerance threshold (PTOL). The maximum duration of holding the hand in the container is 120-180 seconds. The participant does not receive any information about the time limit.

In assessing the results of the described tests, the **Visual Analogue Scale** (VAS) test may be used, which is one of the pain rating scales used for the first time in 1921 by Hayes and Patterson.[44]

participants are asked to indicate the pain level on a scale from 0 to 10. The VAS scale is used to assess the degree of patients' subjective pain in relation to the subjective amount of pain experienced by a given individual in life. The intensity of pain was assessed on a ten-point scale, where zero meant “No pain and discomfort” and 10 meant “The worst possible pain and discomfort.

Practical Applications

For athletes and amateur athletes, moreover, knowledge of pain has another distinctly practical dimension, enabling conscious/informed, because knowledge-based, monitoring of applied loads and control of the body's condition. Decreasing pain indicates that training has been performed correctly, the regeneration processes are taking place, or the post-injury treatment is effective.

The intensity and quality of pain, although these are subjective feelings, can be successfully defined and analyzed in clinical practice as well as in research conducted on physically active people, using established procedures and appropriate tests.

Conclusions

Pain performs an informational and warning function allowing us to avoid situations which are hazardous to our health or life. As for the clinical and physiological aspect of physical effort, pain has an important diagnostic function, indicating the site of an injury and the ongoing pathological processes.
Both excessive physical effort and a lack of physical activity are factors that increase the risk of pain. Physical activity, especially training in athletes, exerts loads on the locomotor system structures and by means of the nociceptive system signalises potential hazards through pain. At the same time, these very same loads trigger the processes activating the endogenous analgesia systems. In the case of intense and prolonged physical activity, these systems are subject to adaptation as well as exhaustion.

Ethical Committee approval

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Informed Consent Statement

Topic

Sport Science.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Declaration if used ChatGPT

We didn't used ChatGPT.

Author-s contribution

Conceptualization, M.P. and K.L.; methodology, M.P.; software, MC.; validation, M.P.,K.L. and M.C..; formal analysis, K.L.; investigation, M.P.; resources, M.P. and K.L.; data curation, K.L.; writing—original draft preparation, M.P.,K.L. and M.C.; writing—review and editing, M.P. and K.L. M.C.; visualization, M.P.; supervision, M.P. and K.L.; project administration, M.C. All authors have read and agreed to the published version of the manuscript.

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