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Pain Perception in Contact Sport Athletes: A Scoping Review

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Short title : *Pain in contact sports*

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ABSTRACT

Contact sports athletes are regularly facing acute physical pain in part of their sport. However, the literature investigating pain perception in these athletes remains scarce. This scoping review aimed to explore the literature surrounding pain perception in contact sport athletes and to compile and understand how it is studied. The search strategy consisted of using index terms and keywords in Medline, EMBASE, SPORTDiscus, Web of Science, PsycINFO, CINAHL and ProQuest Dissertations & Theses Global search engines. Results from 11 studies revealed that a mix of team contact sports and combat sports are studied and included under the umbrella of contact sports. These athletes are being compared to non-athletes as well as athletes from non-contact sports. The cold pressor test and the pain pressure test are the two predominant methods used to investigate physical pain. This review highlights the need to clearly define sports based on contact levels expected in play to better define the types of pain athletes are facing in their practice. Athlete's level of play as well as years of experience should also be more rigorously reported. While contact sport athletes seem to have a higher level of pain tolerance than both active controls and non-contact athletes, the methods of pain testing are not always justified and appropriate in relation to the pain induced during contact sports. Future experimental studies should use pain testing methods relevant to the pain experienced during contact sports and better justify the rationale for the choice of these methods.

243 words

Key points (2-3 sentences summarizing, in non-technical language, the key findings/implications of the manuscript)

- Contact sports athletes are regularly facing acute physical pain in part of their sport.
- This scoping review identified a scarce literature on pain perception in contact sports athletes and highlights the need to dissociate combat sport from team sport athletes due to the nature of their respective sports.
- This scoping review also provide perspectives for future research and definitions to consider when investigating contact sports.

1 INTRODUCTION

Pain is “an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage” [1] and serves as an alarm for avoiding such damage. The primary purpose of that warning in sport is to caution against possible harm such as injury or overwork [2]. Sport participation can however encourage athletes to push past those signals in pursuit of performance goals [2]. Pain can interfere with athletes’ motor control, endurance, and cognitive performance, making it an important component of training or competition outcomes [3, 4]. It, therefore, stands that the relationship between athletes and pain is complex.

Not all painful stimuli encountered by athletes are the same. Pain can develop naturally in the muscle with repeated or continuous contractions [5], a sensation often alluded to with training slogans such as “no pain, no gain”[6]. This exercise-induced muscle pain, also referred to as naturally occurring muscle pain during exercise [5], is likely caused by a combination of increased internal pressure, tissue deformation during contraction and the accumulation of noxious metabolites [7]. Nociceptors (afferent type III and IV fibres or Aδ and C respectively) respond differently to these stimuli with a subset of type IV responding preferentially to muscle contraction under ischaemic conditions, and both fibre types responding to metabolites [7]. Those in a sport where contact is encouraged or required, however, face the additional challenge of having to endure harm purposely done to them by other players. This can represent an additional external mechanical stimulus and would trigger pain pathways associated with skin and muscle deformation, associated or not with tissue damage, rather than those originating naturally in the muscle during exercise. The combination of these experiences result in the overall perception of pain [7]. While it does not exist exact ethical and objective methodologies to replicate the pain from contact sport, the literature in pain research provides several testing methods that could be used to explore pain perception in contact sport.

Pain exists on a spectrum that can be characterized as a function of stimulus intensity and can be investigated from pain threshold to pain tolerance. [8]. The pain threshold is widely defined as the point at which that sensation becomes painful to the participant, and pain tolerance is the maximum intensity of a pain-producing stimulus that a subject is willing to accept in a given situation [8]. Pain threshold and pain tolerance can be investigated via different ways of inducing pain experimentally. The pain pressure test, for instance, relies on increasing mechanical pressure applied externally over a body part [9]. Thermal pain can be induced in two ways, either by using a cold or hot temperature. The cold pressor test requires that the participant immerse a limb in cold water until they are no longer able to withstand the pain [10]. Alternatively, cutaneous heat can be applied similarly by immersing a limb in water or using radiant/laser heat sources or contact probes [7]. Transcutaneous electric stimulation can also be applied to induce pain [7]. On top of external methods applied on the skin, several options are available to induce pain within muscles. This can be induced by the application of topical stimuli or injection within the muscles known to stimulate muscle nociceptors or by the completion of physical exercise. In the context of the application of external stimuli, muscle ischemia involves interrupting blood flow using a cuff to induce local hypoxia and reduce clearance [11]. This method will stimulate the muscle nociceptors by trapping the metabolites within the muscles as well as by the application of mechanical pressure on the skin and the muscle where the cuff is located [12]. A more invasive method consists of the injection of noxious chemicals such as hypertonic saline or a mix of exercise-produced metabolites within a muscle to simulate claudication [7] as well as metabolite buildup [13]. In the context of muscle pain induced by physical exercise, naturally occurring muscle pain [14] and delayed onset muscle soreness (DOMS) are two methods used for the investigation of pain. Naturally occurring muscle pain during exercise occurs during aerobic exercise at an intensity and duration that creates an accumulation of metabolites within the muscles known to stimulate the nociceptors, such as bradykinin or hydrogen ions [5]. Delayed onset muscle soreness (DOMS) can be induced through exercise, causing muscle damage to create a painful condition that peaks 48h after completion [15].

As athletes progress in training and experience, they seem to be able to tolerate more pain than their non-trained counterparts. A review by Tesarz et al. [16] looked at different measurements of pain, both naturally occurring and externally occurring, to compare athletes to non-athletes and found that overall, athletes have a higher pain tolerance than normally active controls. They did not, however, make a distinction between different types of athletes in accordance with the nature of pain of their sport (e.g., endurance vs contact sport). More recent studies extended these results by demonstrating differences in pain perception between endurance and strength athletes [17], as well as triathletes and non-athlete participants [18]. Contact sport athletes differ from others in that they must accept opponents making physical contact with them as part of engagement in the game.

Team sports that fall under that category, such as rugby, have certain rules against excessive physical harm, but some roughness is to be expected, and can in fact be encouraged [19]. Combat sports not only have this expectation but require regulated aggressive, pain-inducing actions to win [20]. Pain during combat sports is caused primarily by external mechanical stimuli applied to the body. It is therefore likely possible that the pain experienced by contact sport athletes is different than the pain experienced by non-contact sport athletes, such as endurance athletes, who are predominantly facing pain induced by metabolic stimuli resulting from muscle contraction-induced metabolic accumulation within the muscle milieu. In this context, studying pain in contact sport as separate is necessary given the difference in pain profiles with other types of sport.

This scoping review aims to explore whether contact sport athletes perceive pain differently, paving the way for future research to test whether natural ability or specific athletic training can influence pain processing. It will explore how pain experienced during contact sport is researched through four research questions. It will ask i) what sports are being studied as well as ii) the expertise level of the athletes. Alongside the athletes in question, iii) the types of control groups being used will also be examined. Finally, iv) the methodology used to induce pain will be scrutinized. While some methods of inducing pain may be more practical, or accessible in a laboratory-controlled environment, not all may be appropriate when testing people with specific sports training if the goal is to generalize to the sport experience.

2 METHODS

2.1 Search Strategy

A librarian (DA) captained the database searches based on those used by Tesarz et al. [14], in collaboration with AOF. The search strategy consisted of using index terms and keywords in Medline, EMBASE, SPORTDiscus, Web of Science, PsycINFO, CINAHL and ProQuest Dissertations & Theses Global search engines. The terms "contact sport", and "pain" were initially used to parse out studies where pain testing was done with the athletes of interest. The detailed equation search for MEDLINE is available in Supplementary Material 1. The search in the database was performed on the 26th of April 2021. Covidence software (Veritas Health Innovation) was used to perform article screening in three steps: removing some duplicates, titles and abstracts, and full texts. Two researchers (AOF and WS) agreed on inclusion at each step of the article screening. In the event of a disagreement, a discussion with a third researcher (BP) determined final inclusion. The initial literature search revealed 699 potential studies of interest, and the screening process led to the inclusion of 9 articles. From later exploration of the "cited by" feature of Google Scholar, a tenth and eleventh relevant article were identified and included. The reference list of all included papers was also screened for additional sources. A detailed flowchart of the inclusion process is available in Figure 1.

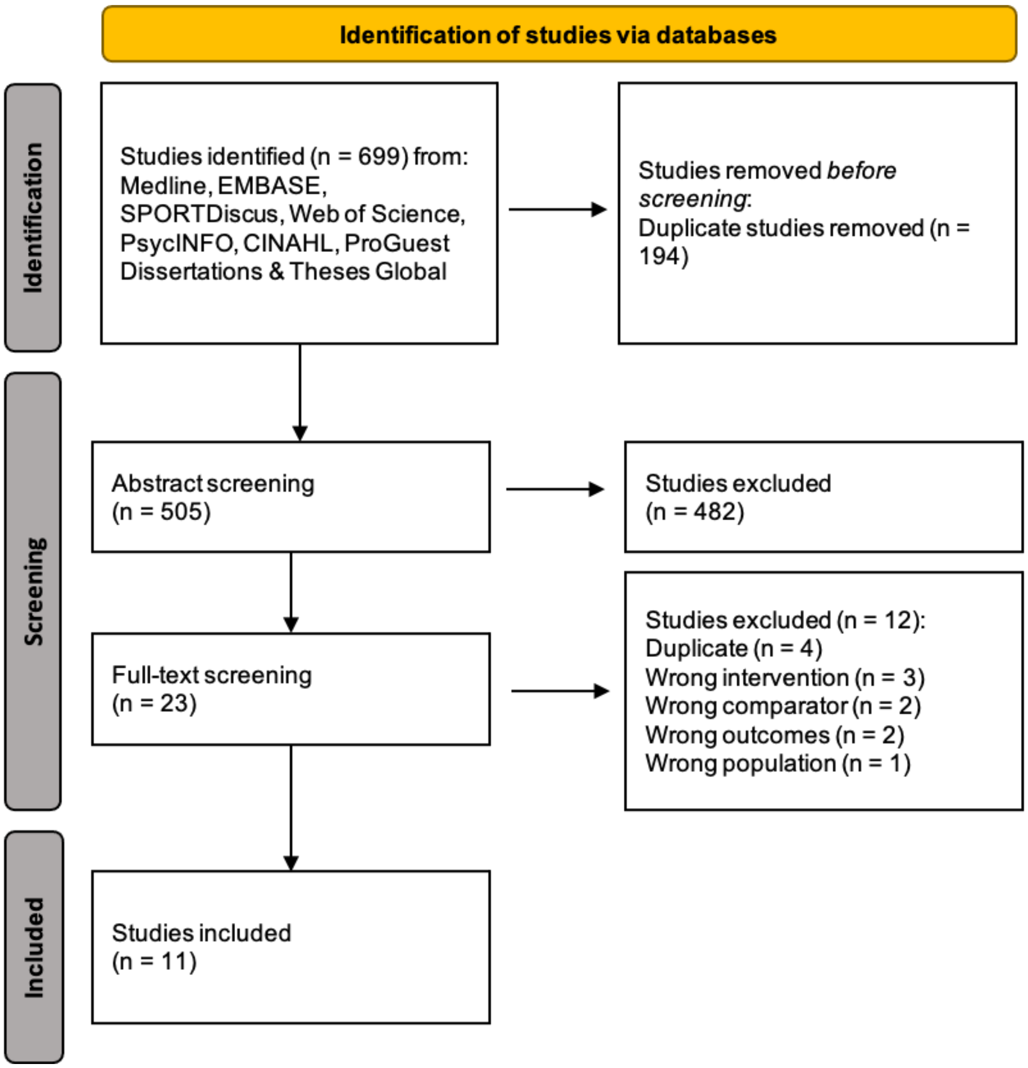

Figure 1: Flowchart of sources screened and included in the present scoping review

2.2 Inclusion criteria

Publications in both French and English were included regardless of publication year. The inclusion of contact sport athletes was the first criterion. Contact sports are defined as any sport where regulated contact with opponents is necessary for play [17] and as such were determined to include combat sports and team sports such as American Football, lacrosse, rugby, roller derby, and hurling. Any additional sport was judged based on whether contact between players is encouraged or is considered part of the game. For example, contact is part of soccer, but not encouraged as a tactical play method. Martial artists were included if their discipline involved physical contact, therefore excluding meditative arts such as tai chi. Controls were either athletes in non-contact disciplines such as tennis, or non-specifically active individuals.

Included studies had to measure pain threshold, tolerance, both, or a continuum from one to the other. Articles using these methods were included as well as reviews including such articles. Comparing pain perception can be done primarily using two different parameters, pain threshold and pain tolerance. Pain threshold is the minimal stimulus necessary perceived by a subject as painful. Tolerance is the upper limit of painful stimulus that a subject is willing or capable of enduring. Both were analyzed to get a better understanding of pain as a multifaceted experience. In some cases, a visual analog scale was used to monitor the pain intensity from the threshold to the point of maximum tolerance. Methods of pain testing had to be validated to be included and so studies using pain pressure test, cold pressor test, electric shock, heat pain, delayed onset muscle soreness, naturally occurring muscle pain during exercise, and ischaemic pain were retained.

2.3 Data extraction

Three authors (AOF, BP, WS) created a data extraction table. A first draft of the table was built by AOF and reviewed by BP and WS. This first data extraction table was then tested by AOF and WS with two articles. Few disagreements were observed, and the three authors updated the data extraction table consequently to obtain the final version available in Supplementary material 2. Data extraction was subsequently performed by AOF and WS, and standardization of the information presented in the table was performed by AOF, BP and WS (see Supplementary material 3). Briefly, for the eleven included articles, the following information was obtained: reference of the article, details of the contact sport and control group, pain tests performed, and other pain-related measurements collected.

3 RESULTS:

3.1 Studies included

To the best of our knowledge, no review focusing on pain in contact sports has been written. Eleven articles were retained for data extraction from the initial 699, all from peer-reviewed journals. Despite searching articles in French and English, all articles retained were in English. Included articles originated from the USA (n = 4), the UK (n = 3), and Poland (n = 4). There was very little overlap between authors from the USA except in the early publications where Ryan appears in both. Two authors from the UK appeared in all three UK-based papers, another author appeared in two. Among the Polish teams, the same first author appears in three of four papers. This fact highlights how few researchers are currently working on pain in contact sports. Both articles written in the 60s were first authored by the same researcher. A timeline of articles published on the subject is represented in Figure 2.

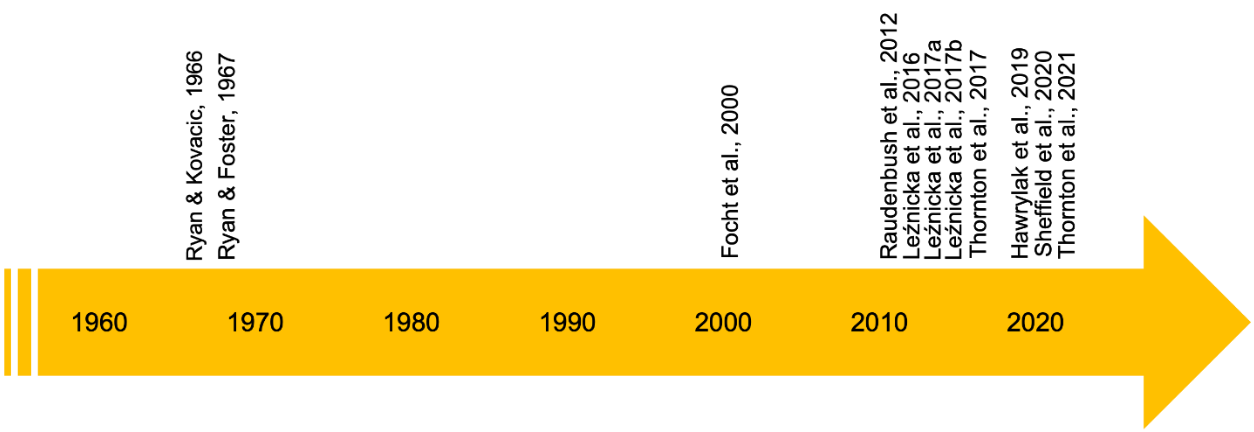

Figure 2. Timeline of studies examining pain perception in contact sport from the 1960s to 2021

Pain perception in contact sports was first studied in the late 1960s [21, 22]. Literature contributing to the topic then ceased being produced until the year 2000 only to ramp up after 2010. The relative density of contributing articles has increased in recent years with eight articles being published in the last ten years.

3.2 Types of contact sport being studied

Reviewed studies recruited athletes from 12 sports (Figure 3). In only two cases [23, 24] did the study draw from a single sport, those being karate and judo, rather than recruit from multiple disciplines. Six studies examined team contact sport and nine included combat sports. All individual sports were combat sports.

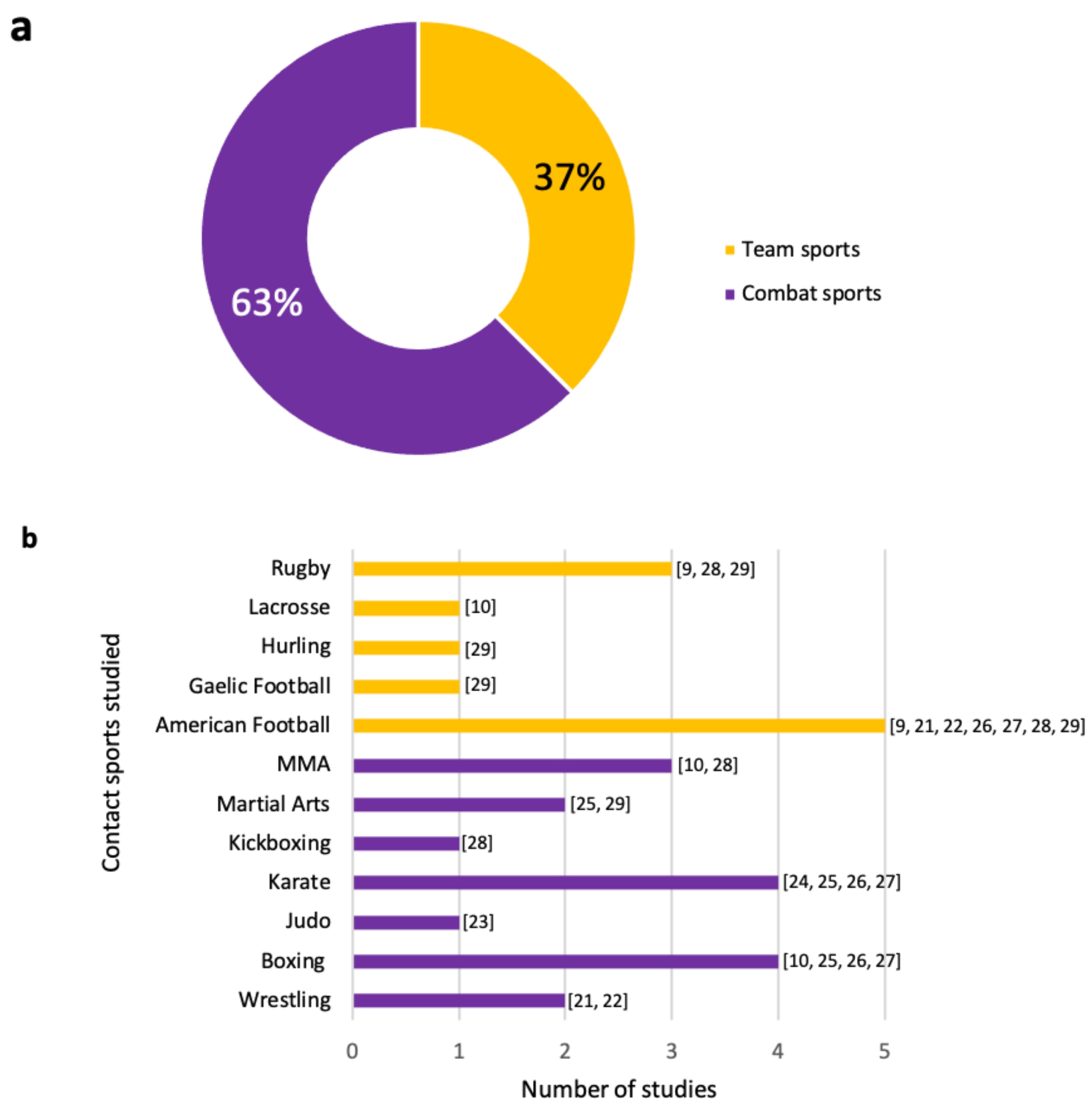

Figure 3. Overview of the contact sports studied: (a) distribution of combat sports and team sports being studied; (b) specific sports. *MMA = Mixed Martial Arts*

3.3 Groups being compared to contact sport athletes

Contact sport athletes were compared to either untrained individuals or fellow athletes trained in non-contact sports (Figure 4). When untrained or non-athletes represented the control group, general levels of physical activity were unclear. In the case of Leźnicka et al. [25-27], the control group was identified as students from the “Physical Culture” department of the university, and no additional information was offered to determine if these students were otherwise active or inactive despite being classified as untrained individuals. In the case of Hawrylak et al. [17], students were also used as a control group, but similarly, no precision was given about the level of physical activity. Sheffield et al. [24] has both types of controls, trained individuals, and untrained individuals. Trained individuals were picked from netball, volleyball, soccer, basketball, track, swimming, and cricket. In no case was a distinction made for low contact team sports such as basketball differing from no contact individual sports such as swimming.

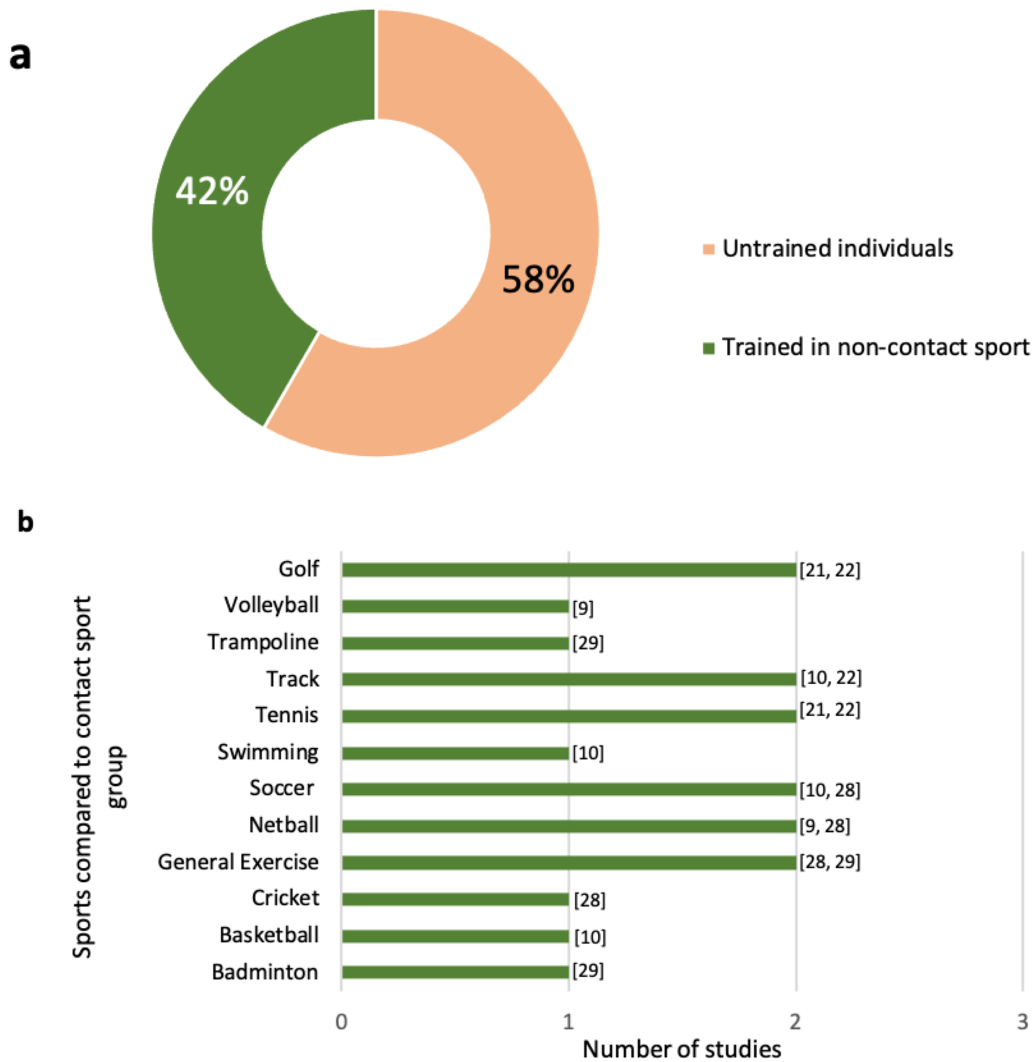

Figure 4. **Overview of groups compared to contact sport athletes**: (a) distribution of untrained individuals compared to individuals trained in a non-contact sport; (b) specific sports practised by the trained individuals.

3.4 Methods of pain testing

Figure 5 represents the methods of pain testing used in the studies included in the scoping review. Of all available methods of pain testing, only four are used across the 11 studies selected:

The pain pressure test, cold pressor test, muscle ischemia, and thermal pain through heat. Two studies used ischaemic pain [22, 23] and it was paired with other methods. Heat pain was used once in the earliest published article [23].

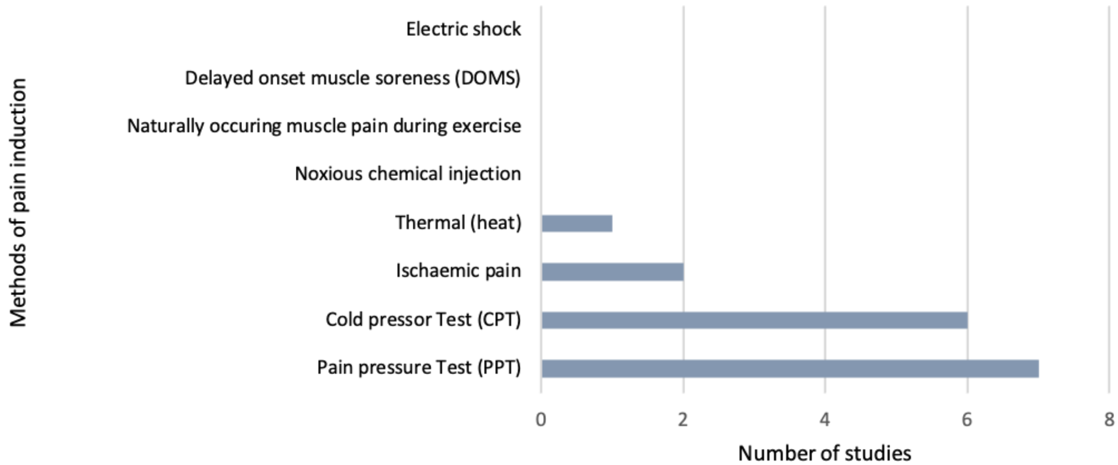

Figure 5. Methods of experimental pain induction.

In the case of pain induced by the pain pressure test (Table 1), all studies showed lower pain perception as reported by contact sport athletes. This is apparent in four studies that showed higher pain threshold, three studies that showed higher pain tolerance, and two studies that showed differences in pain intensity perception.

When studies used the cold pressor test (Table 1), a difference can be seen in pain thresholds. Contact sport athletes, while having similar results in pain tolerance to the pain pressure test, seem to have a similar threshold to cold pain than their counterparts.

An ischemic pain testing protocol (Table 1) found that both contact team and combat sport athletes started out with higher pain tolerance than their counterparts, but that the difference in tolerance increased over time and with added experience (here over 8 months) [28]. Additionally, contact sport athletes showed a higher tolerance than non-contact athletes who in turn showed better tolerance than non-athletes [21].

The one study that used heat as a method of pain induction (Table 1) used it exclusively to determine threshold. The authors noted that beyond a certain point there is no perceptible increase in pain and a ceiling effect could appear [21]

Pain pressure test

Outcomes	*Contact sport included*	*Control group for comparison*	*Results*
Threshold	Combat sport [23, 24, 25, 26]	Non-athletes [23, 24, 25, 26]	Higher pain threshold in contact sport athletes
Tolerance	Team sport [9, 21, 22] Combat sport [21, 22, 25, 26]	Non-athletes [9, 21, 22, 25, 26] Non-contact athletes [9, 21, 22]	Higher pain tolerance in contact sport athletes
Intensity	Team sport [9] Combat sport [24]	Non-athletes [24] Non-contact athletes [9]	Contact sport athletes perceive the stimulus as less painful Decrease in intensity ratings after contact sport training

Cold pressor test

Outcomes	*Contact sport included*	*Control group for comparison*	*Results*
Threshold	Team sport [10] Combat sport [25, 26, 27]	Non-athletes [25, 26, 27] Non-contact athletes [10]	Similar pain threshold to control
Tolerance	Team sport [10, 28] Combat sport [25, 26, 27, 28]	Non-athletes [25, 26, 27, 28] Non-contact athletes [10, 28]	Higher pain tolerance than the control group
Intensity	Team sport [29] Combat sport [29]	Non-athletes [29] Non-contact athletes [29]	Contact sport athletes reported lower pain intensity ratings than controls

Ischaemic pain

Outcomes	*Contact sport included*	*Control group for comparison*	*Results*
Tolerance	Team sport [21, 28] Combat sport [21, 28]	Non-athletes [21, 28] Non-contact athletes [21, 28]	Higher pain tolerance than the control group with a wider gap between groups after experience gain [28] Higher pain tolerance in contact sport group than non-contact sports group. Higher tolerance in non-contact sports group than non-athletes [21]

Thermal pain (heat)

Outcomes	*Contact sport included*	*Control group for comparison*	*Results*
Threshold	Team sport [21] Combat sport [21]	Non-athletes [21] Non-contact athletes [21]	No significant difference in heat pain threshold between contact sport athletes, non-contact sport athletes and non-athletes

Table 1: Outcomes measured, populations and results of each included study.

3.1 Motor and cognitive performance in presence of experimentally induced pain

Motor performance tests [9, 29] were performed simultaneously with the pain condition in two studies to assess the interfering effects of pain. In both cases, the task required participants to throw a tennis ball at numbered targets in a given order. Participants were scored based on their accuracy and speed in completing the task. In Sheffield et al. [8], two conditions were used. In one, the participants had ten targets that they had to hit in numerical order, moving on to the next number regardless of whether they hit the target or not. In the more difficult condition, ten additional targets were added that displayed letters or symbols that had to be disregarded. In Thornton et al. [24], 20 targets were given, and participants were required to hit the one indicated by researchers immediately before the attempt. A total of ten targets were given, and as with Sheffield et al. [8], the participant moved on regardless of having hit the target or not. The grading was also based on time and accuracy.

In both studies, contact sport athletes differed from control groups. In Sheffield et al. [8], high contact athletes' motor performance (both in time and accuracy) was not altered by the pain condition while the low-contact athletes and non-athletes performed significantly worse in the presence of pain. In Thornton et al. [24], experienced contact sport athletes not only maintained their motor performance in the pain condition but hit the targets faster than in the non-pain condition. Novice contact athletes maintained their performance in both speed and accuracy. Non-contact athletes performed significantly worse in both testing parameters when in the pain condition.

Sheffield et al. [8] also had participants perform a cognitive task in both a pain and non-pain condition. The task required participants to check off numbers appearing randomly on a grid in the correct order using pen and paper. The grid contained the numbers one to twenty-five in random order. Performance was assessed using the time taken to complete the task. The difficulty was increased by adding 25 additional numbers that were to be ignored. The pain condition did not alter the performance of the groups regardless of sport expertise.

4 DISCUSSION

This scoping review presents an overview of the literature on pain perception in contact sports. It identifies the types of sports being considered when studying contact sports, the groups they are being compared to, and the various methods used to study pain in those populations. Eleven studies were included, and the literature search did not reveal any reviews focusing on contact sports. The main outcomes of this scoping review were i) an assortment of contact sports were considered across team sports and combat sports; ii) these groups were compared to both non-athletes and non-contact sport athletes; iii) of all available pain testing methods, four were used, two of which may be inappropriate for studying the pain experienced by contact sport athletes in their sport.

4.1 What contact sports are being studied?

The first research question sought to determine which contact sports were being studied. A mix of team sports and combat sports is represented. In two articles, [19, 24] the list of participants' sport affiliations includes "martial arts" with no additional information on the type, expertise level, or contact expected in the sport. As an example, tai chi is a martial art that could technically fall under that umbrella, but it is a meditative discipline where no contact is made as is qigong and non-competitive capoeira [30]. Their inclusion as martial arts can therefore be misleading and introduce population heterogeneity when it comes to pain experience. Similarly, the expertise of participants in contact sports is not thoroughly described in all included studies. Specifying the level of expertise of combat sport athletes as well as their number of years of training is crucial as it conditions the existence and/or intensity of the contact during the activity. To illustrate, it is possible to train in karate without contact while still being considered a martial artist and contact sport athlete. This would be the case for a kata specialist, where performance involves precise movement, but no contact with another karateka [31].

Another challenge with the contact sport groups is the mix of team and combat sport within the same group. It remains difficult to ensure that the level of expertise is similar across dissimilar gameplay requirements [28, 29]. For example, it is not possible to reliably claim that a certain belt in karate is equivalent to a certain level of American Football. Each sport has demands and classifications systems that do not necessarily overlap, and consequently, the quantity and intensity of contact during sport can widely differ between team and combat sports. For instance, light (e.g., knock-out forbidden but continuous actions allowed), semi (e.g., fight stopped at each effective striking scoring a point) and full (e.g., knock-out allowed) contact combat sports regulations indicate different fighting rhythms resulting in distinct contact intensities, still difficult to quantify in practice. In fact, in addition, quantifying any striking on a mobile target (source of contact absorption) is hard to standardise, most of the impact sensors devices are historically bespoke tools relying on gold standard sensing systems such as force plates (REF1) or more recently wearable technologies such as accelerometers attached to limbs or connected to punching bags/pads (REF2, REF3). Moving forward, standardisation of impact sensors tools to produce normative data would be beneficial for future studies. Therefore, by integrating these observations, it appears crucial that future studies adopt a more precise and thorough description of contact sports athletes by providing clear information on sport type and expertise level. Also, due to the different nature between combat sports and team sports, a distinction should be made when pooling participants from both types. We do however keep in mind that such dissociation between combat and team sports could lead to more difficulties in reaching an important sample size depending on the sports clubs existing around the research group performing the studies.

4.2 To whom are contact sport athletes being compared?

The participants included in control groups across the studies varied in level of physical activity. In all cases, those identified as non-athletes were students, and their level of activity was generally unclear or unspecified. This would be important to note since we can refer to Thornton et al. [23] where pain perception changed over months of exposure to contact sports. The literature also suggests that sport practice could alter pain perception regardless of the discipline of contact sport [32]. A thorough description of the history of exposure to contact sport as well as other sports is necessary when comparing pain perception between sport expertise or across physical activity levels in future studies.

As previously mentioned, an identification system detailing the level of contact of each sport should exist to properly classify athlete control groups. For instance, in Sheffield et al. [24], the no contact group was represented by students while the “low-contact group” was comprised of normally active individuals, tennis players, badminton players, and trampolinists. In none of those sports is contact either required or expected for adequate play. The classification of these sports as "low-contact sports" is confusing as the nature of this sport and their rules do not involve contact. Furthermore, as contact sport involves contact with opponents, these sports could not be considered as low contact as the separation between the opponent with a net prevents any contact with the opponent. It appears more appropriate to classify these sports as no-contact sports and to classify team sports such as basketball or soccer as low contact sports. Indeed, in these two sports, while contact between opponents is not predominant, the tactical aspects of the sports require few contacts, such as shoulder to shoulder in soccer or performing a pick and roll in basketball. A more rigorous classification of the control group would therefore be beneficial in future research to truly understand how practitioners of different sports can vary in their pain modulation.

4.3 Proposed definitions for studying contact sports

As presented in the previous section, it exists inconsistencies in the categorisation of the contact sports included in the studies presented in this scoping review. These inconsistencies are apparent in terms of the categorisation of whether a sport is a contact sport or not, as well as in terms of the categorisation of sports according to contact level. As suggested by a reviewer during the peer-review process, this scoping review is therefore an opportunity to provide some clarifications to help conceptualize the notion of (non-)contact sport and low/high-contact sport. To do so, this section will provide brief information on the nature of the contact needed to allow a sport to be categorize as a contact sport, and then offer some definitions.

It is important to clarify that to be categorized as a contact sport, a sport must include contact between at least two opponents. This important detail is explicit in the Collins and Oxford dictionaries where contact sports are defined as "a sport that involves physical contact between participants" and "a sport in which the participants necessarily come into bodily contact with one another", respectively. While some may argue that a certain level of contact may exist in other sports due to the contact with the ground why jumping or running, or the contact with a compliant surface when practicing trampoline for example, we believe that the inclusion of sports including such contact as contact sport is not appropriate. One of the best illustrations may be a marathon runner. During 26.2 miles, a marathon runner will face a contact between her/his foot and the road at each step. However, marathon, as other endurance sports such as trail or other long-distance events are classified as endurance sports due to the nature of the sports not involving contacts between opponents. In this context we propose the definitions below:

- No contact sports: Any sports in which the nature of existing contacts is not between opponents.
- Contact sports: Any sports involving contacts with at least one opponent, and where contacts are regulated by the rules. Contact sports include most of the combat sports and specific team sports.

  Special attention should be given to "martial arts" as some disciplines do not involve contact (e.g., tai chi or qigong), and the level of expertise and years of training may condition the existence or not of contact (e.g., non-competitive capoeira or kata specialist).
- Low contact sports: Any sports in which contacts with opponents may occur but are not essential for play. These contacts are a minor part of the sport and are not extensively encouraged. Such sport may include for example basketball or soccer.
- High contact sports: Any sports in which contacts with opponents are encouraged and essential for play. These contacts are a major part of the sport and are extensively encouraged, albeit compulsory to reach the victory during a game. Such sport may include for example rugby or boxing.

4.4 What methods of pain testing are being used?

Among the available methods existing to study pain in an experimental setting, four were used in the studies included in this scoping review: pain pressure test, cold pressor test, ischaemic pain, and heat pain. The use of the pain pressure test and the cold pressor test dominated within the included studies. When studying pain in contact sports, some methods of testing are less appropriate given that they are not normally encountered in training or competition context (e.g., thermal pain, whether heat or cold, is not typically a painful condition of boxing or rugby). It is however important to note that certain athletes use ice baths for therapeutic or recovery purposes [33], and may therefore be more habituated to the cold feeling or interpret it as healing rather than painful. It would be necessary to ask athletes about their history with this method if using it to induce pain in future studies.

In pain research, certain safeguards are put into place to avoid causing damage to participants. For this reason, the cold pressor test has an upper time limit. This limit is usually not communicated to the participant to avoid creating a target [27]. This can however limit results when it comes to measuring the tolerance of individuals who frequently experience high levels of pain. An individual in a control group and a contact sport group can therefore both have a ceiling effect despite one being able to continue and the other not. It is a crucial limitation to testing that must be considered in the development of further studies.

The source of pain in a combat sport is clear, it is predominately due to mechanical contact with the opponent, however, the pain profile of team sports may have another component, naturally occurring muscle pain that comes with prolonged muscle use. Interestingly, none of the included studies considered the investigation of naturally occurring muscle pain during exercise. This would imply that the choice of the type of pain being induced does not take into consideration possible habituation by a contact sport athlete. The expertise, and therefore possible adaptation, provided by training is not cited as a determining factor. It would therefore be of interest to test this type of pain with other sports to better understand specific pain type modulation required in different sports. Examples include, studying naturally occurring muscle pain during exercise in endurance athletes, or further differentiating pain profiles of team contact sports and combat sports. Additionally, since each athletic pursuit focuses on different aspects of performance (intensity, time, continuity of movement), the muscle pain involved and investigated should have a specific profile based on the sport’s parameters.

4.5 What are the conclusions of the included studies in pain perception in contact sports?

While our scoping review did not aim to perform a meta-analysis due to the heterogeneity in athletes, control groups and pain testing methods in the literature, it remains possible to discuss the outcomes of these studies as presented by the authors. Regarding differences in pain perception, the retained articles measurements of pain threshold, tolerance and intensity were taken. When it comes to measuring threshold, all studies using the same method found similar outcomes for threshold. When using mechanical pain, contact sport athletes were reported to have a higher threshold, consistent with a decreased pain sensitivity. Studies using cold, however, stated that the pain threshold of all groups was similar. This similarity in pain threshold between the different groups is not intuitively surprising as contact sport athletes are not facing cold pain in their practice, and therefore habituation to this specific painful stimulus is most likely not developed, except in the possible case mentioned earlier concerning ice baths. This highlights the possibility that the choice of testing method is crucial when studying contact sport athletes, and that sport expertise could develop pain experience differences that are specific to the nature of the sport performed (e.g., no contact sport athletes are regularly facing painful cold, but do face mechanical pain regularly)

As discussed in the review by Tesarz et al. [14], athletes have a higher pain tolerance than non-athletes. Further distinction between groups of athletes suggests that they are not homogeneous, and differ according to the type of sport. Evidence that tolerance differs across contact categories is consistent throughout all methods tested (pressure, cold, ischemia). Collectively, the results of the retained studies would imply that participation in a contact sport is associated with higher pain tolerance, independent of the pain modality and possibly explained by improved self-regulation of pain. Further study is obviously necessary.

Pain intensity was reported in three studies [9, 24, 29]. Across the cold pressor test and pain pressure test, it was reported that contact sport athletes signal lower pain intensity ratings throughout testing than their counterparts. This result also suggests a generalized hyposensitivity that may reflect a non-specific reduction in pain processing or improved pain-regulation. Future studies should test this observation with naturally occurring muscle pain during exercise and muscle ischemia, two kinds of pain more closely related to sport practice than cold pain.

While cognitive and motor performance in a pain condition was only included in two studies, it would seem like a promising avenue for future research. Maintenance of motor performance in contact sport athletes would imply an ability to endure pain when faced with a physical task and to overcome the interfering effect on motor activity [34, 35] This possibility is supported by the results of Sheffield et al. [8] and Thornton et al. [24]. Cognitively, Sheffield et al. [24] observed that pain did not alter performance and could perhaps be explained by the far more relatable experience of ignoring pain during day-to-day cognitive tasks. Another explanation would be because the negative effect of pain on cognitive performance solely appears in the context of highly demanding cognitive tasks [36]. Future studies interested in the effects of pain on cognitive performance in contact sport athletes should consider modulating the task difficulty to further explore this possibility. Due to the scarce investigation on the effects of pain on cognitive and motor performance in contact sport athletes, future studies are required to a clear conclusion on the effects of pain on performance in this specific population.

5 CONCLUSION AND PERSPECTIVES

When testing pain in contact sport athletes, a heterogeneous spread of both team and combat sports are considered. These athletes are compared to non-athletes or athletes trained in non-contact sports. Pain perception is predominantly tested using the pain pressure test, the cold pressor test, and with ischaemic pain. Naturally occurring muscle pain during exercise being experienced by contact sport athletes, albeit predominantly in team sports, differences between athletes in this specific kind of pain should be considered in future studies. Similarly, DOMS being associated with the experience of muscle pain, and athletes sometimes train or compete in the presence of DOMS, future studies should investigate how the pain experienced in the presence of DOMS could impact contact sport athletes.

More generally, the specificity of the observed differences in a given pain modality should be assessed using within-subject designs including quantitative sensory testing across multiple pain modalities (e.g.[37, 38]).

Further research should consider a more thorough definition of contact sports in opposition to low, or no contact. It should also consider the nature of the pain that sports being tested require athletes to endure to better understand how pain perception can differ in contact sport athletes. Pain threshold and tolerance should be measured given the possibility that one or the other might differ depending on the pain induction technique used. The number of studies examining differences in pain perception in contact sports has increased in the last decade when compared to the first studies in the 60s. It is therefore crucial to adhere to rigorous definitions and justified testing methods to further homogenize the literature. A more rigorous classification of the exact pain profile of contact athletes could also help inform the optimal ways to study them. To our knowledge, no method was used to explore pain caused by impact to bone like that caused by shin-to-shin contact (low kick blocks), or shin to hard surface training equipment (heavy bag, pads) in certain striking sports such as Muay Thai, and Japanese kickboxing (K1)[39, 40]. Future studies should consider using an experimental bone pain model [REF] where an algometer could be applied for example on the shin area rather than on a muscle area.

Further longitudinal studies like the one done by Thornton et al. [28], should also be considered to further parse the role of participation in contact sports in pain perception. If a change is indeed attributed to training, then it would imply that it is not a natural advantage that allows athletes to excel in their sport despite pain, but rather a developed ability. Such longitudinal studies could highlight the mechanisms associated with the development of pain reduction in contact sport athletes.

Finally, as pain is a perception and results from peripheral and central neurophysiological processes, referred to as nociception in the pain literature, future studies should be interested in differences in nociception between contact sport and other athletes. For example, future studies should investigate differences between sport expertise in nociceptive flexion reflex (R-III) which is considered as an index of spinal nociception with tonic supra-spinal influences [41]. Tests of central pain summation (e.g., [17, 38, 42]) or other pain modulation tests, such as heterotopic noxious counter-stimulation (conditioned pain modulation) [17], could be used to assess the efficacy of central pain regulatory mechanisms. Differences in brain responses to painful stimuli and to pain modulation tests between athletes with various sport expertise could further help document possible changes in these central processes.

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