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RESEARCH ARTICLE

The Effect of Swimming on Overuse Injuries in Athletes through Cross-Training Strategy: A Systematic Review

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ABSTRACT

One of the major challenges faced by sports medicine is overuse injuries. Cross-training helps avoid overuse injuries by minimizing the repeated impact on any one muscle or joint. Swimming is a great cross-training option because it is low-impact and works the entire body. Thus, the current study aims to explore the effect of swimming on overuse injuries in athletes through a cross-training strategy. Subsequently, the research questions include: RQ1: Does swimming help athletes experience fewer overuse injuries as a cross-training exercise? RQ2: What effect can swimming have on athletes recuperating from overuse injuries throughout their rehabilitation? RQ3: What are the physiological and biomechanical advantages of swimming that make it a useful cross-training exercise? The study followed a systematic review of 28 works of literature on related topics. Subsequently, the studies were analyzed through thematic analysis. It was found that swimming would reduce the risk of overuse injuries, aiding in rehabilitation. Secondly, it allowed athletes to stay active during recovery while reducing stress on injured areas, making it an excellent choice for joint and ligament injuries. Third, swimming provides physiological and biomechanical benefits, such as improved cardiovascular efficiency, stroke mechanics, and muscular endurance. The study identified limitations such as publication and language bias. However, future studies might follow the findings of this study to conduct a longitudinal study for investigating the role of swimming as a cross-training.

INTRODUCTION

Background

One of the major challenges faced by sports medicine is overuse injuries. Research suggests that 42% of individual athletes suffer from overuse injuries while 33% of team sport athletes suffer from overuse injuries. These injuries are characterized as injuries that occur after repetitive mechanical stress to a tissue which has outweighed its ability to adapt and recover, while also affecting structures such as tendons, muscles, or joints. These kinds of injuries are prevalent in sports involving repetitive activities such as running, cycling or tennis. One common example of such overuse injury is patellofemoral pain syndrome or runner syndrome often found among runners due to repeated trauma to their knees causing wear on the underside of their kneecaps. An additional frequent overuse injury is Achilles tendinopathy, especially in runners and soccer players due in part to the repetitive stress on the Achilles tendon, thus requiring further intervention.

Overuse injuries among athletes have a significant impact on the athletes. These injuries are capable of interrupting the training of an athlete, thereby, they can have long-term effects on performance and overall health. (Franco et al., 2021). In terms of well-being, the mental strain is significant, as many athletes tend to

feel anxious, frustrated, or even depressed during injury rehabilitation. Additionally, athletes in prolonged recovery may experience a loss of competitive ability, while recurring injuries can lead to chronic pain and disability, potentially ending their careers. Due to the psychological and physical toll of these injuries, there is a need for robust preventive strategies for athletes.

Cross-training helps avoid overuse injuries by minimizing the repeated impact on any one muscle or joint. Cross-training provides flexibility, strength, and cardiovascular endurance to other tissues while reducing recurrence risk, as it does not expose the same tissue to repetitive strain. (Mulcahey, 2024). The inclusion of varying modes provides prevention by spreading the mechanical load across body regions, facilitating the recovery of certain areas while preventing detraining in others. This is particularly beneficial compared to other preventive strategies as the same muscle thereby, experiences fewer overuse injuries. Thus, cross-training allows balancing the training load for athletes involved in high-repetition sports, such as running or cycling, where particular muscle groups and joints are usually overused.

Swimming is a great cross-training option because it is low-impact and works the entire body. Swimming, unlike running and cycling, has a low impact on the knees, hips, and back, enabling athletes to maintain cardiovascular conditioning without worsening injuries. (Alkatan, 2015). This can help reduce stress on weight-bearing joints, which is why swimming makes for both a great active recovery tool and an injury-prevention activity. Additionally, swimming involves multiple muscles of the body, increasing core stability and upper extremity strength without overloading specific joints. Thus, it would provide a way to achieve physical recovery while still being physically demanding and enhancing endurance.

Thus, the current study aims to explore the effect of swimming on overuse injuries in athletes through a cross-training strategy. Subsequently, the research questions include:

RQ1: Does swimming help athletes experience fewer overuse injuries as a cross-training exercise?
RQ2: What effect can swimming have on athletes recuperating from overuse injuries throughout their rehabilitation?
RQ3: What are the physiological and biomechanical advantages of swimming that make it a useful cross-training exercise?

By reviewing the effects of swimming, it aims to offer specific guidance for athletes, coaches, and health professionals. This study has the potential to significantly impact how athletes view and use swimming as a cross-training tool for overuse injury prevention and management by providing high-quality, evidence-based recommendations. Subsequently, it would provide a guide on how to use aquatic exercise in training to prevent injuries and enhance recovery. It would not only extend career longevity but reduce healthcare costs related to injury rehabilitation and prevention, given the high prevalence of overuse injuries.

LITERATURE REVIEW

Cross-Training for Overuse Injury Prevention

Cross-training is presumed as an effective method for preventing overuse injuries. A seminal book by Fitzgerald (2004), described cross-training to be particularly successful in providing eight benefits, namely, injury prevention, rehabilitation, greater running fitness, active recovery, enhanced motivation, rejuvenation, enjoying other sports, and fit pregnancy. The author states that cross-training has three modalities namely, flexibility, strength training and endurance training. Similar findings have been found in a study by Rodas (2022). The study involved runners in Camflora National High School who are currently enrolled for the SY 2021 - 2022. It found that runners who incorporated cycling or swimming into their training can keep a high level of cardiovascular fitness with less impact on the legs. Additionally, strength training and low-impact activities such as cycling have also been shown to improve muscle balance, and joint stability, which ultimately has a protective effect against overuse injuries.

Furthermore, a comparative study investigating the reach of cross-training and injury prevention found cross-training provided varied benefits. (Yuspeh, 2021). Strength training lowers the risk of overuse

injuries, mainly in high-impact forms. Cycling and elliptical training are two commonly prescribed activities designed to minimize the risk of injury arising due to repeated impact loads, and swimming's unique biomechanics. However, Rodas (2022) Stated both cycling and swimming are significant tools for cross-training. Most importantly, the study stated that if an athlete is thinking about developing their physique, flexibility, speed, muscles, agility, and balance, swimming should be taken into consideration. This highlights swimming as an important tool to be looked at further.

Swimming as a Rehabilitation Tool

Current research has been looking into swimming as a potential part of cross-training. Resistance training also helps to enhance the power of muscle areas around injured parts which indirectly contributes to better functional recovery (Bennett, 2015). Swimming has a low impact characteristic and, thereby, can be effective for athletes recovering from overuse injuries where buoyancy of water can unload weight-bearing joints, and strains (Wareham et al., 2024). Through the review followed by the authors, the study failed to provide a direct association between low back pain and swimming. However, using the buoyancy of water to overcome gravitational pull and offer resistance aids in building muscle strength and improving joint mobility without stress is capable of aggravating any muscle strain. Thus, it can be useful for patellofemoral pain syndrome and Achilles tendinopathy. Moreover, the review highlights that there are general health benefits associated with swimming but very few examinations investigate its role in overuse injury rehabilitation specific to an athletic population.

Biomechanical and Physiological Benefits of Swimming

Swimming includes distinct biomechanical and physiological advantages. Ploegaerts (2019) Conducted a study on patients suffering from non-specific low back pain. The study utilised water elements for addressing pain in the lumbar region. The buoyancy of water significantly reduces the load on weight-bearing joints, which is particularly beneficial for athletes recovering from overuse injuries. Similar findings have been stated by other studies, such as, Baccouch et al., (2015). The study concluded that swimming can lead to increased joint flexibility, thereby, improving core stability and balance all of which are essential in preventing future injuries.

On the other hand, swimming permits cardiopulmonary and muscle power decreasing the stress positioned on joints, growing overall injury resilience. (Flourizel et al., 2024). Compared to other types of aerobic exercises, such as running or cycling, swimming provides a comprehensive workout and it is not specific to one muscle group or joint. This is because it uses a lot of different muscle groups providing a balanced muscular development which can help avoid overuse injuries caused by one muscle group. However, Flourizel et al. (2024) Stated that while swimming is therapeutic, there is a need to make swimming practice utilize it as a physiological benefit.

Research Gap

Although there is increasing interest in cross-training to prevent injury, research specific to the role of swimming in the prevention and rehabilitation of overuse injuries incurred by athletes appears limited. Moreover, the role of swimming as a cross-training exercise for athletes specifically was lacking. Previous research focused mainly on cycling or strength training as the main cross-training and failed to investigate specific biomechanical and physiological properties provided by swimming. (Rodas, 2022). This understanding highlighted the requirement of more research to investigate swimming efficacy in minimizing overuse injuries and rates of reinjury to lay a foundation for future studies.

METHODOLOGY

Research Design

This study used a systematic review to explore the effect of swimming on overuse injuries in athletes through a cross-training strategy. This approach is particularly relevant in the sports medicine environment, where outcomes can be different depending on the coach and practice contexts related to

individualised sport type or injury. (Yung et al., 2022). A systematic review is the best study design for this study type since it combines and evaluates evidence that was based on focused research questions. (Siddaway et al., 2019). Thereby, a systematic review allows to aggregate, assessment, and analysis of all existing literature to observe patterns or gaps or make recommendations for practice and future research. This is especially useful in sports injury research because studies conducted on small samples, or using different methodologies, prevent a cohesive body of evidence from emerging. The study utilises PRISMA to ensure methodological rigour and transparency in systematic reviews (Figure 1). Thus, this study would aid in addressing the gap in literature, by assessing the potential of swimming presented in different existing studies.

Search Strategy

The study followed a robust search strategy. Literature was searched on databases, namely, PubMed, Cochrane Library, SPORTDiscus and Scopus. Additionally, specific keywords utilised for the search included, "cross-training", "athletes", "overuse injuries", and "swimming". The keywords were applied with Boolean operators such as, AND, OR and NOT. Boolean operators did not limit the search but rather expanded it broadly while keeping data toward identified studies only. Additionally, reports and conference proceedings were also looked into. Furthermore, the study also followed a strict exclusion and inclusion strategy. The inclusion strategy included:

Literature only between 2014-2024 and in the English language

Peer-reviewed literature

Randomized controlled trials (RCTs), cohort studies, and case studies.

On the other hand, review articles, opinions and editorials were excluded. Similarly, studies not focusing on overuse injuries were also excluded. This way, it was ensured that the study was relevant to the research aim and minimised bias. Thus, 30 articles were identified for the study forward.

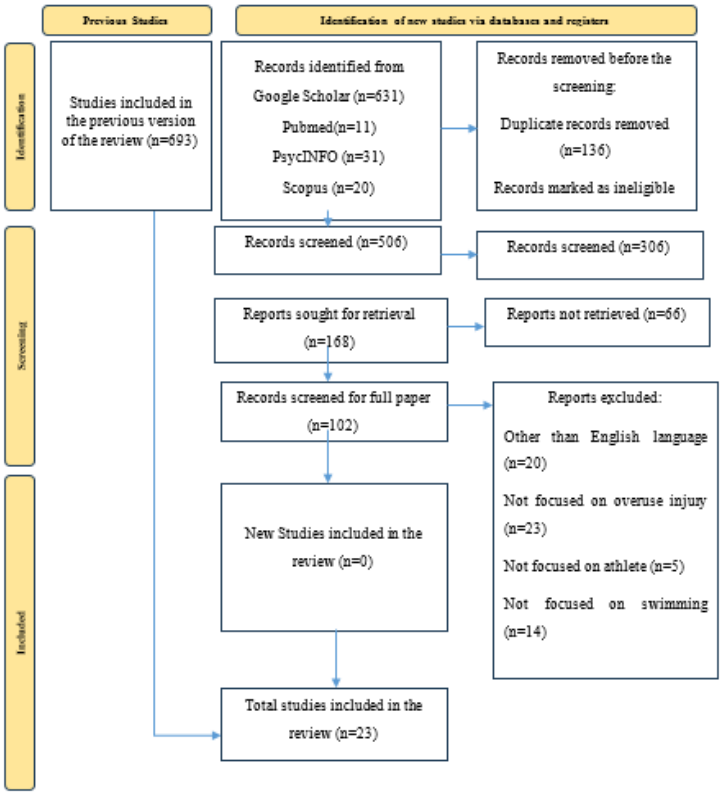

Figure 1. PRISMA flowchart to identify relevant studies.

Data Extraction and Appraisal

The data extraction process adhered to a standardized format. Study characteristics, namely, author, year, population, type of overuse injury, intervention and key outcomes were recorded. Furthermore, the quality of the included studies was assessed with the CASP for RCTs and the Newcastle-Ottawa Scale for cohort studies (Higgins, n.d.). Studies were assigned a rating of low, moderate, or high risk of bias based on these criteria. Thus, these tools provided insight into study types, such as randomization, blinding, and selection bias.

DATA ANALYSIS

The literatures were analysed through thematic analysis. It permits an interpretative organization of data, especially when the findings discussed differ in terms of outcome or methodology (Braun & Clarke, 2012). The literature was read and re-read to identify patterns in the findings. The identified data were then coded and themes were developed. These themes were extracted from the research questions. The review aimed to reduce bias and guarantee that findings were based on high-quality evidence by using an organised methodology with specified methods for data acquisition, assessment, and searching.

FINDINGS

Table 1 highlights the relevant data of the chosen literature. Subsequently, three main themes emerged: Cross-Training to Reduce Overuse Injuries in Athletes, the Role of Swimming in Athletes' Rehabilitation from Overuse Injuries and the Physiological and Biomechanical Advantages of Swimming as a Cross-Training Exercise.

Table 1. List of details for each study included in study.

Author and Year	Aim	Sample	Study Method	Findings	Implications
Baker et al., 2018	The study aimed to investigate the association of age and cross-training among ageing Master swimmers.	499 swimmers	Survey Questionnaire	Sport specific injuries could be reduced through cross-training among the swimmers.	It implies that the swimming when combined with swimming has the potential to decrease injuries.
(Salerno et al., 2022)	To study the injuries among the para swimmers	6 interviews+56 surveys	Mixed Method	There is a need of personalizing the injury preventions.	Swimming affected both para and abled swimmers equally.
(Harrington et al., 2021)	To understand injuries among the elite athletes associated with swimming, cycling and para sport.	144 athletes	Cross-sectional survey	Pain often interferes with training, however, swimmers might have potentially less injury.	It implies that the swimming when combined with swimming has the potential to decrease injuries

					compared to other sports.
Pollen et al., 2021	It aims to determine the relationship between the non-contact musculoskeletal injury and workload.	37 National Collegiate Athletic Association Division III swimmers	Prospective Cohort Study	High worlkload such as ACWRS is associated with injury.	It implied that balanced workload observed in swimming has the potential to decrease injury.
(Grant, n.d.)	It aimed to investigate the high-resistence structured training among swimmers.	9 swimmers	Cohort Study	There is a need for adaptation period while introducing resistance training.	It implied that a structured swimming approach can be beneficial for cross-training.
(Nagano et al., 2019)	It aimed to investigate the overuse injuries from Oslo Sports Trauma Research Centre (OSTRC)	29 female college swimmers	Longitudinal Study	The participants lacked substantial injuries or time-loss injuries.	The study implies that swimming has the potential to reduce lower back injuries.
(Kennedy et al., 2020)	It aimed to investigate and develop "futureproof triathlon"	22 participants	Qualitative study	Multimodal sports such as swimming, cycling, and running has potential benefits to human body.	It implied that swimming can be utilised as a potential preventive measure for overuse injuries.
(Loudon & Parkerson-Mitchell, 2022)	It aims to understand the potential of cross-training with running among the swimmers.	31 female participants	Survey	Cross-training does not appear to be linked to a decrease in self-reported injury rates.	It implies that cross-training has the implication to reduce injuries.
(Kerr et al., 2015)	It aimed to investigate the injuries associated with swimming and diving.	22 swimmers	Survey	Though further study is required, swimmers tend to have less injury compared to divers	Though the study indicated further need of enquiry, the implication of findings in the context of injuries to shoulder.

(Boltz et al., 2021)	It aimed to understand the epidemiology of the study.	Data from 2014-2015 through 2018-2019	Quantitative analysis	Most of the injuries were due to surface contact.	It implies that injuries related to swimming were distinct emphasized on diving.
(Mavrovouniotis et al., 2019)	It aims to understand the effect of exercise on the knee rehabilitation.	296 participants	Quantitative analysis	Mode of weightbearing and resistance bands related exercise aided in better knee recovery.	It implies that swimming can be of better use as an intervention instead of operation.
(Mohammed et al., 2018)	It aimed to investigate the effectiveness Mindfulness Based Stress Reduction (MBSR) among injured athletes.	20 athletes	Quantitative analysis	Increase in pain tolerance aided in increasing mindfulness.	This implied that swimming can aid in decreasing stress.
(Serner et al., 2020)	It aimed to investigate the return-to-sport (RTS) following criteria-based rehabilitation for cute adductor injuries among athletes.	81 athlete	Cohort Study	Low impact exercises during rehabilitation aided in RTS.	It implied that swimming being a low impact movement can be utilised for rehabilitation and pain.
(Prien et al., 2017)	It aimed to investigate the injury among athletes related to Fédération Internationale de Natation (FINA) World Championships 2015 compared with 2013 and 2009.	Participants in Fédération Internationale de Natation (FINA) World Championships 2015	Retrospective questionnaire	The study found less injuries for swimming but more infection.	It implied swimming can be utilised for functional recovery
(Kumar et al., 2021)	It aimed to investigate restoration of after axotomy through	touch neuron circuit of Caenorhabditis elegans	Empirical study	It found that swimming exercise aided in axon regeneration through the	It implied that swimming can be utilised for resotoring functional

	physical exercise.			activity of cellular energy sensor AAK-2/AMPK in both muscle and neuron.	ability among athletes.
(Langdon & Fletcher, 2020)	It aimed to investigate the relation between adherence and rehabilitation engagement.	21 injured athletes	Quantitative analysis	Compared to athletes who start out with low levels of engagement, those who are highly engaged with their rehabilitation show a slower decline in involvement.	It implies that if swimming is applied to cross training during rehabilitation, there will be need of maintaining adherence.
(Veskoukis et al., 2018)	It aimed to investigate swimming performance protocol without suffering.	9 rats	Empirical study	Rats with little variability in time to fatigue can have their swimming performance measured practically and successfully.	It implies swimming can be applied a part of rehabilitation.
(Upadhyaya & Bhatt, 2017)	It aims to investigate the holding capacity in swimming.	35 participants	Empirical study	The study found that respiratory efficiency can be enhanced through respiration.	The ability to increase respiratory efficiency without adding muscular strain makes swimming an excellent cross-training tool for endurance athletes.
(Ferreira et al., 2021)	It aimed investigate physiological, anthropometric and biomechanical variables related to	34 swimmers	Empirical study	Structured plan is required for significant age-group swimming performance.	Swimming enhance energy conservation, making swimming useful for sports.

	middle-distance performance.				
(Kwok et al., 2021)	It aimed understand the biomechanical evaluation in swimming.	954 articles	Meta-analysis	In place of swimming training alone, strength and conditioning training is advised to be incorporated into a regular training regimen due to its beneficial benefits on swimming performance, including starts, turns, front crawl swim, and pertinent biomechanical metrics.	Swimming has potential biomechanical advantages.
(Morais et al., 2018)	It aimed to study the interplay between conditioning and dry-land strength and stroke biomechanics in young swimmers.	27 swimmers	Empirical study	Conditioning in swimming aids in stroke biomechanics.	It implies the potential of swimming through conditioning.
(Pugliese et al., 2015)	It aimed to understand how performance and physiological variables are affected when training volume and intensity are changed.	10 male swimmers	Empirical study	These results suggest that increasing training volume may enhance middle- to long-distance performance and VO2peak in masters swimmers.	It can improve both endurance and strength.
(Bielec et al., 2016)	It aimed to investigate passive	7 collegiate male swimmers	Empirical study	Power output measured through	Swimming aided in recovery of

	recovery among the swimmers on aerobic and anaerobic performance			Wingate test showed improvements.	power abilities.

Cross-Training to Reduce Overuse Injuries in Athletes

Swimming can be considered as a potential therapy for its low-impact nature. Ten of the thirty articles were identified to provide insight into swimming as a cross-training for overuse injuries. Following the patterns in the literature, three more sub-themes were identified: Reduction in Overuse Injuries through Cross-Training, Swimming's Unique Impact on Specific Injury Types, and Balanced Workload Management.

Reduction in Overuse Injuries through Swimming Cross-Training

Various studies indicate that inculcating swimming as the cross-training method can reduce overuse injuries. Baker et al. (2018) Aimed to investigate the prevalence of injuries and the injury rate among athletes involved in swimming. The injury occurrences were aligned with the training habits. Subsequently, the statistical analysis found that swimmers faced relatively low injuries in comparison to other athletes. In this context, multinomial logistic regression for the effect of cross-training on injury rates is an advanced statistical technique that adds strength to the findings. This implies that swimming could be a potential approach as a part of cross-training for the reduction of overuse injuries. The swimmers who cross-trained reported significantly fewer swim-related injuries than the ones who did not.

However, the study did not segregate swimming as one cross-training category alone, so further research is needed to draw definitive conclusions regarding the effects of swimming in isolation on injury reduction. The study focused solely on Masters Swimmers, which also restricts the ability to generalize findings to athletes from other sports. Contrarily, another study focused on para-swimmers stated that swimming might cause overuse injury when used as a primary training modality instead of cross-training (Bennett, 2015). The study showed that 52.4% of the Para swimmers surveyed missed some training due to injury, with shoulder injuries (23.8%) most prevalent. All participants performed strength training, but only a few had a prior engagement in formal injury prevention protocols. These athletes were significantly affected by overuse injuries (primarily of the shoulder) compared to able-bodied swimmers.

Swimming has a low impact on the lower body, but continuous overhead strokes can increase shoulder injury in a swimmer who lacks proper technique or over-trains. Although these studies show the advantages of cross-training, they raise pertinent questions about how generalizable swimming's protective benefits might be. However, Nagano et al. (2019) Adapted the Oslo Sports Trauma Research Centre overuse injury questionnaire for female collegiate swimmers, showing that cross-training could reduce lower back and shoulder injuries. The paper suggests that cross-training among swimmers may be beneficial in reducing injury, but it fails to recognize swimming as a cross-training tool for athletes in other sports. This may suggest the practice of swimming is like any other form of exercise, and that it comes with its risks, while responsible management by careful loading on such activity can promote injury reduction.

Swimming as a Recovery and Rehabilitation Tool

Swimming aids in enhancing recovery and rehabilitation. Harrington et al. (2021) Investigated cross-training in Para athletes and found that swimming was favourably associated with reduced risk of injury recurrence. This study highlighted how swimming can be used for both injury prevention and rehabilitation. Moreover, swimming was a low-impact activity that allowed athletes to maintain overall fitness while aiding recovery. Nonetheless, the potential mechanisms underlying how swimming may negatively interact with different injuries in various athletic populations remain unclear.

Similarly, Pollen et al. (2021) Found that collegiate swimmers who balanced their acute workloads properly through cross-training, including swimming, sustained fewer musculoskeletal injuries during the season. The prospective cohort study of collegiate swimmers also found that high training loads increased the odds of musculoskeletal injuries. The research suggests mixing swimming with other types of training to help balance workloads on joints and muscles, potentially avoiding overuse injuries. However, it lacks direct comparisons of swimming versus other forms of cross-training, limiting its ability to attribute injury prevention specifically to swimming.

Alternatively, another study indicated indirect insights into the potential of swimming as a part of cross-training. Grant (n.d.) found that those who partook in structured resistance training alongside swimming had fewer injuries. The study suggests that more cross-training in swimming would be beneficial. The results help further understanding of a well-rounded training program that balances in-water and out-of-the-water exercises to minimize risks for overuse injuries. However, this study too, highlights the idea that one should not solely rely on a swim program to prevent injury.

Balanced Workload Management

One significant pattern emerged highlighting the importance of managing training loads to prevent overuse injuries. Various studies highlight abrupt increases in workload volume, particularly acute workloads, are linked to higher injury rates. (Nagano et al., 2019; Pollen et al., 2021). However, these studies caution against relying solely on swimming to balance training loads. Kennedy et al. (2020) found that triathletes who incorporated swimming into their training had fewer overuse injuries related to running and cycling, showing swimming's versatility as a cross-training tool with low impact yet high intensity(Kennedy et al., 2020). While swimming is an excellent low-stress alternative, it should be integrated into a comprehensive training program that addresses the specific demands of the athlete's primary sport. For instance, athletes in high-impact sports may need to adjust their swimming routines differently than those in low-impact activities.

Furthermore, Loudon and Parkerson-Mitchell (2022) study on female Masters runners found that cross-training, including swimming, reduced running-related injuries and highlighted swimming's cardiovascular benefits while minimizing joint stress. This study focuses on triathletes, limiting its broader application to other athletes. However, it focused solely on running injuries, offering little insight into how swimming might affect injury rates in athletes from other sports, particularly those involving upper-body movements.

Role of Swimming in Athletes' Rehabilitation from Overuse Injuries

Stress coupled with inadequate recovery and relaxation time between workouts or competitions make overuse injuries common in athletics. Subsequently, three sub-themes were identified: swimming as a low impact rehabilitation tool, enhanced functional recovery and reduced pain, and adherence and psychological benefits.

Swimming As a Low Impact Rehabilitation Tool

Swimming is one of the most efficient means of physical therapy that can helps athletes in recovering from overuse injuries as it is one of the low-impact form of exercise. The study by Kerr et al. (2015) and Boltz et al. (2021) highlighted that swimming allows athletes to remain active during recovery while reducing while healing their injuries by lowering loads on the injured areas. Additionally, Boltz et al. (2021) further argue that the buoyancy of water reduces stress on joints enables the full-body movements with less risk of re-injury. Alternatively, Kerr et al. (2015) mentioned that collegiate athletes are at high risk for overuse injuries, especially in the shoulders and lower extremities, but swimming can reduces tension on joints compared to land-based rehabilitation exercises like running or cycling. This is particularly helpful for athletes rehabilitating lower extremity injuries, as they can maintain cardiovascular fitness and muscle strength without stressing recovering tendons and joints. This exercise helps bridge the gap between inactivity and full physical recovery. However, the low-impact nature of swimming has some risks. Kerr et al. (2015) caution that overuse injuries, particularly shoulder injuries, can occur even during rehabilitation

if proper stroke mechanics and workload management are not maintained. This highlights the need for supervision and technique adjustments to minimize injuries during rehabilitation.

Functional Recovery and Pain Management

Swimming has been concluded as one of the most effective activities to enhance functional recovery and ensure successful pain management during rehabilitation. Mavrovouniotis et al., (2019) determined that aquatic exercises like swimming are useful for the athletes in case of treatment after knee ligament injuries due to their positive influence on joint mobility and general function without any painful feelings. The non-impact, full-body movement capability of swimming in a low-resistance environment enhances recovery by increasing blood flow and decreasing inflammation, crucial for tissue repair. However, swimming may not address the complexities of all overuse injuries. While helpful for joint recovery and pain reduction, swimming alone may not be sufficient in advanced rehabilitation phases where higher resistance and functional movements are needed for a full return to sport. Thus, it is essential for rehabilitation programs to integrate swimming with other land-based exercises as athletes progress.

Similarly, Mohammed et al. (2018) reported a significant reduction in pain perception and improved coping with psychological stress when swimming was combined with mindfulness-based interventions. In this regard, swimming aids both physical and mental recovery, blending various healing techniques into rehabilitation. Consistent with past research, aquatic exercises improve range of motion, reduce muscle stiffness, and enhance neuromuscular function, making swimming an essential component of rehabilitation protocols. In this context, Serner et al.(2020) that low-impact exercises like swimming supported faster recovery times and fewer reinjuries due to the reduction in stress on injured areas. This study is particularly relevant based on the rehabilitation strategies for acute adductor injuries.

Most significantly, a study assessing injuries during aquatic competitions found that overuse injuries were common, but swimming-based recovery strategies, including low-impact training, significantly helped athletes recuperate. (Prien et al., 2017). The efficacy of swimming in rehabilitation varies depending on the type of injury. Whereas. Studies such as Mavrovouniotis et al. (2019) have presented swimming relating to the rehabilitation of the knee, there might be other situations where the universality may not apply. The overuse injuries to other parts of the body for example, tendons and ligaments-may not be as responsive to aquatic therapy only. For instance, a study investigating axon regeneration post-injury found that swimming as a rehabilitation exercise promoted faster functional recovery, particularly by enhancing neural regeneration mechanisms.(Kumar et al., 2021). While swimming can aid rehabilitation for some injuries, it is not a one-size-fits-all solution. The extent to which swimming benefits recovery depends on the injury's severity, location, and the individual athlete's biomechanics.

Psychological Benefits and Adherence to Rehabilitation Programs

Swimming addresses an often overlooked but crucial aspect of rehabilitation, that is, the psychological dimension. Studies like (Langdon & Fletcher, 2020) Mohammed et al. (2018) show that swimming increases adherence to rehabilitation programs and improves mental health. Injured athletes who engage in swimming-based rehabilitation tend to report lower levels of anxiety and stress, which boosts their engagement in the rehabilitation process. The meditative nature of swimming, combined with the calming effects of being submerged in water, can significantly enhance an athlete's motivation to stay on track for successful recovery.

However, the psychological benefits of swimming should not be overstated about physical recovery. Langdon and Rb (2020) found that while athletes who enjoyed swimming adhered better to their rehab, enjoyment alone cannot replace structured rehabilitation that addresses physical imbalances. The risk lies in viewing swimming as a complete solution when it should be integrated into a broader rehabilitation program, including land-based exercises and conditioning.

Additionally, not all athletes will experience psychological engagement with swimming. While it may be enjoyable for some, others might find it monotonous or insufficiently challenging. As seen in studies like

Mohammed et al. (2018), swimming alone may not provide the depth of focus and motivation necessary for athletes used to more dynamic training. Thus, rehabilitation programs should consider individual preferences and psychological readiness when incorporating swimming.

Physiological and Biomechanical Advantages of Swimming as a Cross-Training Exercise

Swimming has long been recognized as a low-impact exercise that offers substantial cardiovascular and muscular benefits. The remaining papers discussed the cardiovascular benefits, biomechanical efficiency, and overall power gains that swimming can offer as a cross-training exercise. Subsequently, three subthemes were identified: Low-Impact Nature and Cardiovascular Efficiency, Biomechanical Efficiency and Adaptations and Physiological Adaptations and Power Gains.

Low-Impact Nature and Cardiovascular Efficiency

Several studies underscore swimming's unique advantage as a low-impact exercise that minimizes muscle damage while still providing a highly effective cardiovascular workout (Veskoukis et al., 2018). Unlike running or cycling, which impose repetitive stress on the joints, swimming offers athletes a way to train for endurance without subjecting their bodies to significant musculoskeletal strain. Analysis of these findings suggests that swimming is particularly effective for maintaining cardiovascular fitness during recovery periods or in athletes prone to injury. However, it should not be relied upon exclusively for athletes whose sports require significant impact endurance, as the cardiovascular gains may not fully compensate for the lack of weight-bearing exercise.

This is particularly important for athletes in high-impact sports who are prone to overuse injuries. The study by Upadhyaya et al. (2017) further highlights the respiratory benefits of swimming, as breath-holding capacity is significantly enhanced in swimmers compared to sedentary individuals. The ability to increase respiratory efficiency without adding muscular strain makes swimming an excellent cross-training tool for endurance athletes. However, despite these benefits, there are limitations in terms of how well swimming translates to land-based endurance performance. The non-weight-bearing nature of swimming means that while cardiovascular fitness may improve, the specific muscular demands of land-based sports may not be fully addressed.

Biomechanical Efficiency and Adaptations

The biomechanical advantages of swimming are another critical theme. Studies by Ferreira et al. (2021) and Morais et al. (2018) emphasize how regular swimming leads to improvements in stroke mechanics, particularly stroke length (SL) and stroke index (SI), which contribute to overall performance efficiency. In sports like running or cycling, where biomechanical efficiency is crucial for energy conservation over long distances, swimming helps athletes become more biomechanically aware and efficient. These improvements in stroke mechanics are not only important for swimming performance but also highlight swimming's potential role in improving coordination and efficiency in other sports. For example, the ability to refine movement patterns and make small, precise adjustments in stroke length can have carry-over benefits to running stride efficiency or cycling cadence. However, while swimming offers biomechanical benefits, these gains are sport-specific and may not always translate to land-based movements. For athletes whose primary sport involves different movement patterns, swimming's biomechanical benefits must be complemented with sport-specific drills to ensure maximum cross-training efficiency.

Physiological Adaptations and Power Gains

Swimming also provides significant physiological adaptations, particularly through high-intensity interval training (HIIT) protocols. Studies such as Pugliese et al. (2015) and Bielec et al. (2016) demonstrated that swimming at high intensities improves both aerobic and anaerobic capacity. These studies show that high-intensity swimming protocols can enhance VO2 peak, anaerobic threshold, and overall power output, making it an excellent cross-training tool for athletes seeking to improve both endurance and strength. Bielec et al. (2016) reported that sprint interval swimming improved power output and swim speed,

emphasizing the role of swimming in strength development. This finding is particularly relevant to athletes of strength-dependent sports-for example, football or track and field-who can utilize swimming as a supplementary exercise in developing power without the associated muscle damage common to high-impact, strength training. While compelling, these gains are also somewhat sport-specific physiologically from swimming. For explosive power sports, including weightlifting, the magnitude of power gains in the athletes may not be as great as it was with the endurance athletes. Swimming's power development tends to focus more on muscular endurance and high-repetition, low-impact work, which may not entirely transfer to sports with a focus on maximal strength.

5. DISCUSSION

5.1. Potential of Swimming in Reducing Overuse Injuries

Swimming can be an effective cross-training method for reducing overuse injuries due to its low-impact nature on the lower body. Research shows that swimming helps athletes maintain cardiovascular fitness without stressing the joints, making it a useful option for high-impact sports like running and cycling. Studies by Baker et al. (2018) and Nagano et al. (2019) suggest that swimming, when included in training regimens, can lower injury rates, particularly for lower-body injuries, by providing recovery without overloading the musculoskeletal system. However, these studies primarily involved swimmers and further research is needed to assess swimming's effectiveness for other athletes.

Although swimming offers advantages, it also poses risks, particularly for upper-body overuse injuries such as shoulder injuries caused by repetitive overhead movements (Bennett, 2015). Both Para and able-bodied swimmers are susceptible to shoulder injuries, highlighting that while swimming reduces lower-body stress, it may increase the risk of upper-body overuse if performed excessively or without proper technique. Studies indicate that high training volumes, improper stroke mechanics, and limited cross-training variety may contribute to these injuries. (Wang et al., 2020). Thus, swimming should be paired with strength training and workload management to prevent shoulder overuse injuries.

Balanced workload management is essential when using swimming for cross-training. Abrupt changes in training intensity or duration are linked to higher injury rates. (Fredette et al., 2022). Therefore, combining swimming with other cross-training methods, such as resistance or flexibility exercises, provides a more holistic approach to injury prevention (Harrington et al., 2021). While swimming offers significant cross-training benefits, it should be part of a broader injury prevention strategy tailored to the athlete's sport and training demands.

5.2. Effect of swimming on athletes recuperating from overuse injuries throughout their rehabilitation

Swimming has gained popularity as a rehabilitation tool for overuse injuries due to its low-impact conditioning. Studies have shown that aquatic therapy reduces strain on injuries, allowing athletes to stay active without further harm (Kerr et al., 2015; Boltz et al., 2021). This aligns with research highlighting water's buoyancy and resistance, which enable athletes to perform movements without stressing joint structures (Wilk & Joyner, 2024). Supportive resistance in water also minimizes joint loading. However, swimming poses risks for the upper body. Shoulder overuse injuries are common in swimmers and may worsen during rehabilitation if technique and workload management are not carefully monitored. Therefore, swimming, while beneficial, must be supervised and planned to prevent further injuries.

Swimming has also been well-documented as a method for pain relief and functional restoration. Aquatic exercises like swimming improve joint mobility, boost circulation, and reduce inflammation and muscle stiffness. Xiao et al. (2023) Found that cold-water immersion accelerated recovery and reduced muscle soreness post-exercise. Swimming also enables a full range of motion without the high resistance or impact seen in land-based exercises. However, the study suggests that swimming alone may not address all recovery needs, especially in advanced rehab stages, where higher resistance training is required to restore strength.

Psychologically, swimming enhances rehabilitation adherence by reducing stress and anxiety (Mohammed et al., 2018). Jackson et al., (2022) Similarly found that aquatic exercises improve mental well-being and decrease depressive symptoms in injured athletes. While swimming promotes mental health and rehabilitation engagement, it should not be solely relied upon for its psychological benefits. As Langdon and Rb (2020) suggest, swimming must be part of a comprehensive rehabilitation plan that includes land-based training to fully restore both physical and mental health.

5.3. Physiological And Biomechanical Advantages Of Swimming

Swimming as a cross-training exercise provides several physiological and biomechanical benefits due to its low-impact nature, cardiovascular efficiency, and ability to enhance power and biomechanical adaptations. Swimming promotes cardiovascular efficiency by increasing aerobic fitness while reducing musculoskeletal load. (Biró et al., 2020), making it ideal for runners or cyclists who want to avoid joint stress. However, the lack of weight-bearing stress limits its effectiveness for land-based sports like long-distance running or basketball, where both cardiovascular fitness and load-bearing capacity are necessary.

Biomechanically, swimming improves stroke mechanics, increasing stroke length and efficiency, which boosts overall performance (Ferreira et al., 2021). These adaptations improve coordination and accuracy, which can enhance energy conservation, making swimming useful for sports like running and cycling, where movement efficiency is vital (Kwok et al., 2021). However, since swimming's movement patterns differ from those of land-based sports, athletes in sports like tennis or soccer may need additional drills to transfer these gains effectively. Physiologically, swimming HIIT improves both aerobic and anaerobic capacity, enhancing power output (Papandreou et al., 2020). Its low-impact, endurance-focused nature makes it great for building muscular endurance without injury risks. However, while it suits endurance athletes, power gains from swimming may not fully support the explosive strength needed for weightlifting or sprinting. As such, while swimming offers notable benefits, its adaptations are best complemented with sport-specific strength training.

CONCLUSION

Swimming was observed to be a cross-training modality, reducing the risk of overuse injuries, aiding in rehabilitation, and offering various physiological and biomechanical advantages. Its low-impact nature makes it ideal for athletes who need to stay active while reducing injury risk, especially in high-impact sports like running and cycling. Research shows swimming helps prevent lower-body overuse injuries by providing recovery without musculoskeletal overload. However, swimming can increase the risk of upper-body overuse injuries, particularly in the shoulders, making proper technique and workload management crucial. This highlights the importance of balancing swimming with other forms of cross-training, such as resistance and flexibility exercises, for a more complete injury prevention strategy.

The benefits of swim rehabilitation are well documented. Swimming allows athletes to stay active during recovery while reducing stress on injured areas, making it an excellent choice for joint and ligament injuries. However, supervision and careful technique adjustments are necessary, especially for shoulder overuse injuries. While swimming supports pain control, joint mobility, and mental well-being, it must be combined with land-based exercises in a comprehensive rehabilitation program for full physical recovery and strength restoration. Additionally, swimming provides physiological and biomechanical benefits, such as improved cardiovascular efficiency, stroke mechanics, and muscular endurance. While swimming builds both aerobic and anaerobic capacity, its adaptations are sport-specific and may not fully support power-dependent sports. Therefore, while swimming offers significant benefits, it should complement sport-specific training to maximize its cross-training effects.

Despite the strong findings, this study was limited due to the research design. The inclusion of the published study could inculcate publication bias. Additionally, the study might be limited by the inclusion criteria of only following one language, subsequently, increasing the chances of losing important works. However, the inclusion and exclusion criteria would ensure minimizing these potential biases. Thereby, future studies

could undertake longitudinal research to further investigate the conclusions drawn from this study. These findings would be significant in paving novel pathways for designing personalized cross-training with swimming.

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