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Wheelchair Basketball: morpho-functional and physiological aspects of the shoulder
Baloncesto en silla de ruedas: aspectos morfofuncionales y fisiológicos del hombro

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Abstract. Wheelchair basketball is one of the most popular paralympic sports. It is a great physical activity that guarantees important health benefits and promotes the well-being and social inclusion for disabled people. At the same time, wheelchair basketball involves a significant risk of injuries for wheelchair basketball players and upper limbs are the most burdened body segments. In particular, sport specific gestures lead to progressive overload of the shoulder joint, which usually results in shoulder pain. For these reasons, scientific and technological progress should improve the development of rehabilitative strategies to promote shoulder health and then to reduce shoulder pain. Within the spectrum of new technologies, electromyography is a tool that allows real-time measurement and to take advantage of the potentiality of biofeedback, so it has been used previously to improve the outcome of rehabilitation treatments. Therefore, the purpose of this review is to summarize and analyze the current evidence regarding the use of electromyography, as a rehabilitative strategy, to reduce shoulder pain in wheelchair basketball athletes. Following the PRISMA statement guidelines (PROSPERO - 2023, n° CRD42023470395), a total of 10 studies met the inclusion and exclusion criteria after a search of three databases (Pubmed, Google Scholar and Cochrane Library). The result of this review highlights the importance of electromyography and surface electromyography in the prevention and treatment of shoulder pain in wheelchair basketball athletes. Moreover, this examination emphasizes that using surface electromyography as a biofeedback seems to be an effective way to speed up shoulder pain rehabilitation outcomes in wheelchair basketball athletes.
Keywords: exercise; sport; technologies; rehabilitation, physiology.

Resumen. El baloncesto en silla de ruedas es uno de los deportes paralímpicos más populares. Es una gran actividad física que garantiza importantes beneficios para la salud y promueve el bienestar y la inclusión social de las personas con discapacidad. Al mismo tiempo, el baloncesto en silla de ruedas implica un riesgo significativo de lesiones para los jugadores de baloncesto en silla de ruedas y las extremidades superiores son los segmentos corporales más cargados. En particular, los gestos específicos del deporte conducen a una sobrecarga progresiva de la articulación del hombro, lo que generalmente resulta en dolor de hombro. Por estas razones, el progreso científico y tecnológico debería mejorar el desarrollo de estrategias de rehabilitación para promover la salud del hombro y luego reducir el dolor de hombro. Dentro del espectro de las nuevas tecnologías, la electromiografía es una herramienta que permite medir en tiempo real y aprovechar la potencialidad del biofeedback, por lo que se ha utilizado anteriormente para mejorar el resultado de los tratamientos de rehabilitación. Por lo tanto, el propósito de esta revisión es resumir y analizar la evidencia actual sobre el uso de la electromiografía, como estrategia de rehabilitación, para reducir el dolor de hombro en atletas de baloncesto en silla de ruedas. Siguiendo las directrices de la declaración PRISMA (PROSPERO - 2023, n° CRD42023470395), un total de 10 estudios cumplieron con los criterios de inclusión y exclusión después de una búsqueda en tres bases de datos (Pubmed, Google Scholar y Cochrane Library). El resultado de esta revisión destaca la importancia de la electromiografía y la electromiografía de superficie en la prevención y el tratamiento del dolor de hombro en los atletas de baloncesto en silla de ruedas. Además, este examen enfatiza que el uso de la electromiografía de superficie como biorretroalimentación parece ser una forma efectiva de acelerar los resultados de la rehabilitación del dolor de hombro en atletas de baloncesto en silla de ruedas.
Palabras clave: ejercicio; deporte; tecnologías; rehabilitación, fisiología.

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Introduction

Wheelchair basketball is a paralympic sport born in the 1940s as a rehabilitation strategy for veteran of II World War (Akbar et al., 2011). Nowadays is one of the most popular adapted sports for people with physical impairments (Bates et al., 2019; Battel, & Walshe, 2023). and according to IWBF (International Wheelchair Basketball Association) it is played in over 100 countries by approximately 30,000 players worldwide (Blauwet, 2019).

Rules of WB are similar to those of stand-up basketball, except for essential adaptation due to the use of wheelchair for moving around the court. Another peculiarity is related to the rules of classification score, specifically to the class assigned to each athlete based on residual functional abilities. A classification score, ranging from 1.0 to 4.5, is assigned to each athlete. In order to make the competition fairer and to minimize the impact of each athlete's impairment during the game, the total score of the five athletes on the field must not exceed the value of 14 during international competitions of the International Wheelchair Basketball Federation (IWBF).

WB is a sport with intermittent efforts that requires high-intensity activities with long periods of recovery. For this reason, it determines high aerobic and anaerobic demands (Castroflorio, Bracco, & Farina, 2008; Corvino et al., 2020; Guerra et al., 2014; Silva et al. 2022).

As known, physical activity and sport skills leads to important benefits for people (Cavalcante et al., 2022; Farì et al., 2022), in particular for people with disability (Ferreira et al., 2022; Aidar, 2022). Especially WB guarantees a decrease in urinary tract infection and improvement in

biochemical and immunological systems (Juul-Kristensen et al., 2022). Moreover, WB promotes mental health and social participation with a better psychological profile and self-acceptance (Juul-Kristensen et al., 2019). Another important aspect which guarantees these benefits to people with disability is related to motivation. Athletes have to be engaged in competitions and trainings and previous study demonstrates how WB players participate in this sport with the aim to reach personal goal and to challenge with peers, even more than able-bodied basketball players (Najafabadi, 2023).

Regarding youth population participation in sports represents a fundamental aspect (Kamonseki, Calixtre, Barreto, & Camargo, 2021) and it has been demonstrated that young WB athletes display more hedonic well-being than people with disabilities not taking part in competitive sports (Karasuyama, Oike, Okamatsu, & Kawakami, 2023; Latino & Tafuri, 2024a). Furthermore, WB allows young people to participate in enjoyable and healthy physical activities, build relationships, experience recognition for achievement, and (re)create a positive sense of self-identity. The opportunities carried by participation in this sport enable young athletes with disabilities to grow and achieve in these ways without the burden of stigma, challenges and constraints they may encounter in other sports and social contexts (La Torre et al., 2023). In this perspective, WB creates an "enabling place" which can enhance disabled people's well-being and social inclusion (Latino, & Tafuri, 2023, 2024a,b).

WB is at the same time a high impact sport which involves a significant risk of injuries for athletes. Compared to other wheelchair athletes, WB players are the second most injured athletes and during the Paralympic competition of London 2012 and Rio 2016 the incidence rates was of, respectively, 12 and 12.8 injuries per 1000 athlete-days (Willick, 2013; Derman, 2018). This data became even higher during the WB World Championships 2018, where the incidence rate recorded was of 68.9 injuries per 1000 athlete-days (Hollander, 2020). Injury risk is related to contacts and falls and to continuous overload that respectively involve traumatic and overuse injuries. Furthermore, a more recent epidemiology study in a population of elite WB athletes during a whole season, it was reported that women, aged 35–70 years, experienced higher rates of health problems, illnesses and injuries compared to men of the same age (Muscogiuri et al., 2016; Rocca et al., 2016; Weith, Junge, Rolvien, Kluge, & Hollander, 2023). Upper limbs are the most affected body segments (Latino, Greco, Fischetti, Cataldi, 2019) and, in particular, shoulder joint is the anatomical district most frequently burdened by these problems, especially by overuse injuries (Latino, Cataldi, & Fischetti, F., (2021).

Sport specific gestures of WB (e.g., wheelchair propulsion and repeated overhead movements), low mechanical efficiency and poor trunk control leads to a progressive overload of shoulder that usually results in shoulder pain (SP). SP is also influenced by many various factors such as use of the wheelchair in activity daily life, age, gender, and type of disability (Latino et al., 2022) and the importance of this issue has led to the development of a specific pain scale, the Wheelchair User's Shoulder Pain Index (WUSPI) scale, in order to assess the SP in wheelchair users (Latino et al., 2023). Although SP is a common problem in wheelchair users (Farì et al., 2021), it becomes even more pronounced in WB athletes (Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group*, T., 2009). In fact, according to the recent scoping review conducted by Karasuyama et al., SP has a high prevalence in this population which ranges from 38% to 75%, with an incidence rate of 14% (Morsanuto, Peluso Cassese, Tafuri, & Tafuri, 2023).

SP is not only a limitation of quality and intensity of training, and consequently for sport performance (Neblett, 2016), but it can even compromise the daily life activities reducing independence level of wheelchair users (Latino et al., 2023). For these reasons, scientific and technological progress should aim to improve the development of rehabilitative strategies to promote shoulder health and then to reduce SP.

The interest in the use of technological systems designed to support sports activities, both in terms of performance evaluation and assessment of injury risk and regarding the rehabilitation phase, is increasingly growing in the world of sports (Windt, 2020 - Alcantarilla-Pedrosa, 2021; Kakavasa, 2021). Within the spectrum of new technologies, electromyography (EMG) is a tool used to measure the muscle's electrical activity. Particularly, surface electromyography (sEMG) is a type of EMG which provides non-invasive information on muscle properties through electrodes placed on the skin. The simplicity of application of this technique determined the wide-spread use of sEMG in clinical and research fields (Puce et al., 2023). Moreover, sEMG allows detecting in real-time muscle activity and to take advantage of the potentiality of biofeedback, thus it has been used to enhance the result of rehabilitation treatments (La Torre et al., 2023; Rayes, Ball, Lee, & White, 2022). In fact, sEMG biofeedback is one of the most used types of biofeedback applied with the aim to manage pain and enhance rehabilitation program (Giggins, 2013) and, particularly, previous studies focused on the use of sEMG biofeedback for the treatment of chronic pain. In particular, the sEMG biofeedback was used in addition to a traditional exercise schedule for patients with chronic low back pain and this form of enrichment of traditional exercise seems to lead to a significant increase in strength of lumbar muscles (Rice, Peters, Fliflet, Sung, & Rice, 2022).

To date, other reviews have discussed the use, alone or in combination with other technique, of EMG for SP treatment. Specifically, the systematic review and meta-analysis conducted by Kamonseki et al. investigated the effects of EMG biofeedback in a population of men and women aged 18 years or older with SP (Riek, Pfohl, & Zajac, 2022). Another recent systematic review selected studies conducted on adults with SP managed non-surgically in order to

investigate whether physiotherapy interventions, included EMG, were used as additional tools after suprascapular nerve block injections as treatment for chronic SP (Rufo, Ferreira, Camargo, & Fernandes, 2021). Although the importance of the evidence reported in the above-mentioned reviews, none of them focused exclusively on wheelchair users and in particular in those who regularly practice WB. At the same time, scientific research should focus and deepen on the use of new technologies, such as EMG, which could make treatments more personalized and specific, as needed by wheelchair users (Cratsenberg, 2015). Therefore, this review aims to summarize and analyze the current evidence regarding the use of EMG, as a rehabilitative strategy, in order to reduce SP in WB athletes.

Methods

Search Strategy

This review was carried out following the PRISMA statement guidelines (Sà et al., 2022). The databases used for the identification of scientific articles were PubMed, Google Scholar and Cochrane Library. Candidate studies were identified by using the following Boolean search syntax: "((Electromyography or "surface electromyography") and ("shoulder pain" or "wheelchair basketball")"/"("morpho-functional and physiological aspects") and (rehabilitation or "shoulder pain))". Afterwards, the following filters were activated—text availability: full text; species: humans; languages: English; period: last five years. The search syntax employed for the PubMed database was a mix of the MeSH database and Boolean search syntax. After candidate articles were collected, further selection was performed according to the inclusion and exclusion criteria.

Identification of Studies

Studies were identified through a search of three databases (Pubmed, Google Scholar and Cochrane Library). At the end of the selection process, 870 articles were extracted, of which n = 513 from Pubmed, n = 200 from Google Scholar and n = 157 from Cochrane Library. Studies were identified by searching for studies of likely relevance to the review. Duplicates have been eliminated (n = 59). Thus, every title and abstract were selected, removing review articles, unpublished studies, meta-analyses, case studies, practical guidelines and books (n = 657). Subsequently, the full text of the remaining 154 articles was assessed to verify their eligibility. Finally, 10 research articles were included (figure 1).

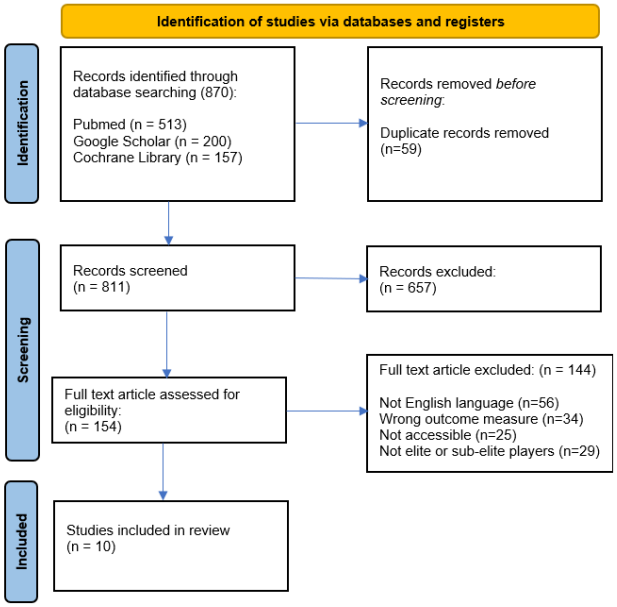

Figure 1. The study selection and eligibility screening flow according to PRISMA guidelines.

Selection Criteria

If the studies provided relevant information on PICOS system and met the set-out inclusion criteria, they were considered eligible for inclusion. The inclusion criteria were:

- English-language publications;
- Time interval of studies between 2018 and 2023;
- S-EMG as tool of diagnosis of shoulder pain;
- Study design: randomized controlled trials;
- Intervention: WB.

Studies were excluded if they did not meet the above criteria, or due to the lack of focus on S-EMG and shoulder pain in WB. Review articles, meta-analysis, and unpublished studies were excluded from this work, although they were used as a reference to identify the original search to examine for inclusion. The Jadad Scale (modified version) was used to select the studies in a qualitative way (Table 1). It was used to assess the methodological quality of the studies selected and included in this systematic review.

Table 1.
The modified version of Jadad quality scale.

Authors	Was the treatment randomly allocated?	Was the randomization procedure described and was appropriate?	Was there a description of withdrawals and dropout?	Was there a clear description of the inclusion/exclusion criteria?	Were the methods of statistical analysis described?	Jadad score (0-5)
Juul-Kristensen et al. (2022)	No	No	Yes	Yes	Yes	3
Farì et al. (2022)	No	No	Yes	Yes	Yes	3
Farì et al. (2022)	Yes	No	Yes	Yes	Yes	4
De Oliveira et al. (2022)	Yes	Yes	Yes	Yes	Yes	5
L M Riek et al. (2022)	Yes	Yes	Yes	Yes	Yes	5
Kristensen et al. (2019)	Yes	Yes	Yes	Yes	Yes	5
Garcia Gomez et al. (2019)	No	No	Yes	Yes	Yes	3
Swanson et al. (2020)	Yes	Yes	Yes	Yes	Yes	5
Rufo et al. (2021)	No	No	Yes	Yes	Yes	3
Sui et al. (2022)	No	No	No	Yes	Yes	2

As recommended by the Cochrane for the evaluation of risk-of-bias an excel graph was used (Figure 2). It allows to highlight the transparency and methodological rigor and was performed for each included study.

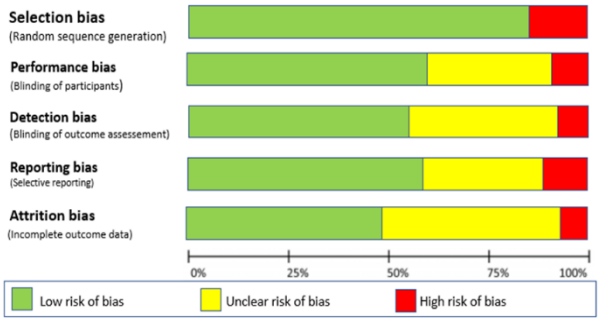

Figure 2. Risk of bias assessment graph.

Results

Study Characteristics

This systematic review considered an analysis of 10 high-quality studies focused on s-EMG and shoulder pain in WB. The summary characteristics of reviewed studies were the follow:

Table 2.
Summary characteristics of reviewed studies.

Authors	Title	Sample	Measures	Results
Juul-Kristensen et al. (2022)	Assessment of shoulder rotation strength, muscle co-activation and shoulder pain in tetraplegic wheelchair athletes - A methodological study.	Twelve adult tetraplegic wheelchair players (WCR) athletes	WUSPI and VAS measured shoulder pain, isometric HHD and ID measured maximum internal and external shoulder rotation strength. S-EMG measured muscle activity (mm Infraspinatus and Latissimus Dorsi) during maximum shoulder rotation strength.	Isometric HHD is comparable with ID on normalized peak torques and muscle activity, but with larger co-activation. Strength was not clearly associated with shoulder pain.
Farì et al. (2022)	Real-Time Muscle Activity and Joint Range of Motion Monitor to Improve Shoulder Pain Rehabilitation in Wheelchair Basketball Players: A Non-Randomized Clinical Study	Thirty-three wheelchair basketball (WB) athletes divided into two groups	Both groups underwent a shoulder rehabilitation protocol, but only the experimental group was monitored in real time with sEMG on the shoulders. At enrollment (T0), at the end of 4 weeks of the rehabilitation program (T1), and 8 weeks after T1 (T2), were collected WUSPI, 20 m straight line test and ROM.	The experimental group showed better improvement at all timepoints than the control group. sEMG appears to be a useful tool to improve monitoring of SP rehabilitation outcomes in WB players.
Farì et al. (2022)	Could the Improvement of Supraspinatus Muscle Activity Speed up Shoulder Pain Rehabilitation Outcomes in Wheelchair Basketball Players?	Thirty-three wheelchair basketball (WB) athletes divided into two groups	Both groups underwent the same shoulder rehabilitation program, but only the Exercise Plus sEMG Biofeedback Group executed therapeutic exercises while the activity of the supraspinatus muscles was monitored using sEMG. Participants were evaluated at enrollment (T0), at the end of 4 weeks of the rehabilitation program (T1) and 8 weeks after T1 (T2), using supraspinatus muscle activity as root mean square (RMS), WUSPI, shoulder abduction and ROM.	The Exercise Plus sEMG Biofeedback Group improved more and faster for all the outcomes compared to the Exercise Group. The monitoring and improvement of supraspinatus muscle activity seems to be an effective way to speed up SP rehabilitation outcomes in WB players
de Oliveira et al. (2022)	Comparing exercises with and without electromyographic	24 patients with subacromial pain	The patients were randomized to either therapeutic exercise or exercise	The addition of Biofeedback to the exercise protocol increased

	biofeedback in subacromial pain syndrome: A randomized controlled trial		plus biofeedback to the trapezius and serratus muscles. Pain and shoulder function were evaluated as the primary outcome and ROM, muscle strength, electromyographic activity and scapulohumeral kinematics as secondary outcomes.	upward rotation of the scapula.
Riek et al. (2022)	Using biofeedback to optimize scapular muscle activation ratios during a seated resited scaption exercise	Fifteen subjects (12 males and 3 females) without shoulder pain	Comparison of the effects of three types of biofeedback (visual EMG, auditory, verbal cues) on UT/SA and UT/LT ratios during a seated resisted scaption exercise. Baseline muscle activation was recorded and compared to real-time muscle activation during each randomized biofeedback trial.	Visual EMG biofeedback training during a resisted scaption exercise can improve scapular muscle ratios while allowing participants to remain seated.
Juul-Kristensen et al. (2019)	Positive effects of neuromuscular shoulder exercises with or without EMG- biofeedback, on pain and function in participants with subacromial pain syndrome – A randomised controlled trial	49 participants with a minimum amount of pain and actual pain; divided in 2 groups: BIONEX (26) and NEX (23), with 3 participants in BIONEX and 2 in NEX lost to follow-up.	A single-blinded two-group parallel superiority RCT was conducted, investigating the effect of 8weeks of supervised EMG-biofeedback neuromuscular shoulder exercises (BIONEX group), versus neuromuscular shoulder exercises only (NEX group). Baseline and follow-up testing after 8 weeks intervention included self-reported outcomes, placement of surface electrodes, performance of maximal voluntary isometric contractions (MVIC) for EMG normalisation, and standardised arm tasks.	In summary, EMG-biofeedback did not seem to make a difference. As both BIONEX and NEX were effective in reducing pain to a clinically relevant level, the current neuromuscular shoulder exercise protocol can be recommended to patients with subacromial pain syndrome.
Garcia-Gomez et al. (2019)	Effect of a Home-based Exercise Program on Shoulder Pain and Range of Motion in Elite Wheelchair Basketball Players: A Non-Randomized Controlled Trial	Thirty-six WB players, assigned to either an exercise or a control group, according to the use of the wheelchair during daily activities	The participants were either allocated to an intervention group, performing a resistance and stretching shoulder exercise program (n = 12), or a comparison group receiving the standard recommendation (n = 14) . Assessments were performed at baseline and after 10 weeks. A questionnaire was used to assess what kind of activities players carried out during the study. The shoulder pain index for the wheelchair basketball players (SPI-WB) questionnaire was used to assess SP	Shoulder Pain did not increase along the 10 weeks of the SHEP development in WB players who reported SP before the intervention program. However, in those players who started the intervention without SP, as no increase in SP was observed and players were free of injury. An exercise program could be a tool to maintain shoulder health and prevent injuries in elite WB players.
Swanson et al. (2020)	Changes in glenohumeral translation, electromyographic activity, and pressure-pain thresholds following sustained or oscillatory mobilizations in stiff and healthy shoulders: Results of a randomized, controlled laboratory trial	88 participants,(44 control, 44 stiff shoulders)	Participants were randomly assigned to one of two mobilization conditions. Pre-post intervention measurements of PPT, glenohumeral (GH) translation via ultrasound imaging, and RC activity assessed via electromyography were performed. Sustained or oscillatory grade III posterior GH mobilizations were then provided to all participants.	Sustained mobilizations resulted in greater changes in GH translation. RC activity was higher in the stiff shoulder group, and remained higher post-intervention despite gains in GH translation, suggesting a me- chanical rather than neurophysiologic effect.
Rufo et al (2021)	Changes in electromyographic activity of deltoid muscles in women with shoulder pain during a functional task	22 women aged (44 ± 10) who were divided into two groups: 11 women with shoulder pain and 11 women without shoulder pain.	The muscle activity evaluation was performed using surface electromyography of the muscles: anterior deltoid, middle deltoid, upper trapezius and middle trapezius, during an isometric task of arm elevation in the scapular plane	Results revealed a significant increase in the activity of the anterior and middle deltoid muscles in women with shoulder pain compared to women without shoulder pain in the isometric task of arm elevation. It was concluded that the shoulder pain of the women evaluated caused changes in the activity of the anterior and middle deltoid muscles.
Sui et al. (2022)	Analysis of Muscular Electrical Activity and Blood Perfusion of Upper Extremity in Patients with Hemiplegic Shoulder Pain: A Pilot Study	13 healthy subjects (Healthy group), 13 hemiplegic patients with shoulder pain (HSP group), and 14 hemiplegic patients without shoulder pain (HNSP group)	In this observational and cross-sectional study, three groups of participants were recruited. The sEMG data and blood perfusion data were collected from all the subjects and used to compute three different physiological measures, the root-mean-square (RMS) and median-frequency (MDF) parameters of sEMG recordings, and the perfusion unit (PU) parameter of blood perfusion imaging.	This study indicated that the muscular electrical activity of upper extremity had a correlation with the presence of HSP, and the blood perfusion seemed to be no such correlation.

Discussion

The purpose of this review is to summarize and analyze the current evidence on the use of EMG as a rehabilitative strategy to reduce SP in WB athletes. Specifically, the sEMG allows the detection of real-time muscle activity and has the potential of biofeedback. Thus, it has been used to enhance the results of rehabilitation treatments. We already know, according to García-Gómez et al. (2019), that an exercise program is able to maintain shoulder health and prevent injuries (Mazzeo et al., 2016; Messina et al, 2015; Seron, de Carvalho, & Greguol, 2019). Therefore, we want to investigate whether the use of sEMG, in addition to a rehabilitation program, reduces the SP in WB player and improves the outcomes. Most of the studies analyzed have demonstrated the usefulness of EMG in preventing or treating shoulder pain. Nevertheless, not all the studies included investigate SP's treatment in WB. This could be a limitation, but we attempted to avoid it by including articles with a comparable population. It could be useful make further studies evaluating sEMG in this specific populations to highlight differences with WB's athletes with and without SP.

In a non-randomized clinical study Farì et al. (2022) demonstrate that the sEMG is a useful tool to improve monitoring of SP rehabilitation outcomes in WB players. In particular, the experimental group showed better results at all timepoints in a more rapid and marked way than the control group. The global joint functionality was restored better by significantly reducing SP. They asserted that complete rest is impossible with any therapy, as the upper limbs are essential for daily activities in these subjects. Hence, the need of a promptly and effective rehabilitation (Smith, Liew, Johnson, Ellard, Underwood, & Kearney, 2021). In a following study, Farì et al. show the higher improvement of supraspinatus muscle RMS (Root Mean Square, used to measure the amplitude of EMG) that coincided with a greater and faster rehabilitation. The supraspinatus is one of the most frequent causes of WB players' shoulder pain. This study was conducted on two groups of WB athletes and resulted that the Exercise Plus sEMG Biofeedback Group improved more and faster for all the outcomes compared to the Exercise Group.

Although, in 2019 Birgit Juul-Kristensen et al. said that the EMG-biofeedback did not seem to make a difference. A two-group single-blinded parallel superiority RCT was conducted, investigating the effect of 8weeks of supervised EMG-biofeedback neuromuscular shoulder exercises (BIONEX group), versus neuromuscular shoulder exercises only (NEX group). Significant improvements have been made by both groups, along with a clinically significant change. Actually, in the BIONEX group there was a superior improvement (0.18 point) than in the NEX group (Sporner, Grindle, Kelleher, Teodorski, Cooper, & Cooper, 2009).

As stated in the study of Brian T. Swanson et al. (2020) EMG can be also used to assess shoulder pathologies before, during and after rehabilitation (Sui et al., 2022). They founded those stiff shoulders showed a higher baseline rotator cuff (RC) activity than controls, which may have caused a decrease in glenohumeral translation. The authors suggest that there is a connection between the augmented RC activity and high levels of pain, which may have implications in clinical practice.

Rufo et al (2021) (Swanson, McAuley, & Lawrence, 2020) affirmed that the shoulder pain produces an alteration in muscle activity between anterior and middle deltoid muscles. This resulted in a greater muscle activation in the shoulder with pain. This increased muscle activation, with deepen investigations, could be read as a warning bell in the diagnosis of SP, helping in early detection of SP and in the rehabilitation of the affected muscles. Also in other sports that require physical exertion similar to those investigated in this study, it is possible to observe these problems but with lower incidence (less than 44%) (Valencia et al., 2024). For example, in a study that involved twelve tetraplegic wheelchair Rugby (WCR) athletes, Juul-Kristensen et al. (2022) detected that strength, evaluated with s-EMG, was not clearly associated with shoulder pain (Villacieros, Pérez-Tejero, Garrido, Grams, López-Illescas, & Ferro, 2020). The measurement scales were WUSPI and VAS.

According to the work conducted by de Oliveira et al. on 24 patients with subacromial pain, the addition of EMG-Biofeedback to the exercise protocol increased the superior rotation of the scapula, however, it did not influence the improvement of shoulder pain and function (Weith et al., 2023).

On the other hand, in an observational and cross-sectional study, Sui M et al (Yıldırım, Büyüköztürk, Bayramlar, Özengin, Külünkoğlu, & Çoban, 2019), found that the single pain symptom has a correlation with the reduction of activities of both affected and non-affected shoulder muscles. They recruited three groups of participants: hemiplegic patients with shoulder pain (HSP group), hemiplegic patients without shoulder pain (HNSP group), and healthy participants (Healthy group). The RMS parameter of sEMG showed significant difference ($p < 0.05$) in the affected side between HSP, HNSP, and Healthy groups. This indicated that the muscular electrical activity of upper extremity had a correlation with the presence of SP.

Riek et al. (2022) have compared, during a resistive caption exercise sitting in fifteen subjects without shoulder pain, the effects of different types of biofeedback (visual, auditory EMG, verbal signals) on upper trapezius/serratus anterior and upper trapezius/lower trapezius ratios. Each randomized biofeedback study recorded and compared basic muscle activation with real-time muscle activation. The UT/SA and UT/LT ratios were improved by all types of biofeedback, with visual EMG indicating a significant change in the UT/LT ratio ($p < 0.05$). The use of biofeedback as a part of rehabilitation programs to prevent or treat

shoulder pain is suggested by these findings (Yildirim, Comert, & Ozengin, 2010).

Although this work provides a support concerning the positive relationship between s-EMG and shoulder pain in WB players, the boundaries of this review are the relative lack of long-term trials, and of studies with a wider sample size, as s-EMG is a quite new tool in this specific subject. Therefore, it is recommended that future research explore these factors in order to expand knowledge and improve the state of the art. Nevertheless, the findings achieved may give significant directions for next studies. In fact, the strength of this work is to provide significant findings about a useful tool with diagnostic value in identifying and preventing shoulder pain.

Conclusions

This review highlights how the use of EMG and s-EMG is important in the prevention and treatment of shoulder pain in all subjects in general and, what concerns us the most, in WB players in particular. Above all, s-EMG is a valid and useful tool as it is non-invasive. S-EMG helps us to see the changes inducted by the pain in muscle activation, therefore, to diagnose SP. In addition, using it as biofeedback allows us to tailor rehabilitation programs to the patient, to improve the outcomes and to have better and faster results. Further studies are needed to demonstrate the importance of activity monitoring and how it improves rehabilitation protocols, nevertheless the current results already seem promising to build new horizons to avoid or treat shoulder pain in wheelchair basketball players. Currently, studies in literature presented a small population. So, it would be useful to expand the study sample in new clinical trials. Another point to future investigation could be the comparation between several rehabilitations' type to state the best exercises program. Furthermore, clinical trials should investigate effects of various types of biofeedback in long term or with longer training.

Author Contributions

Conceptualization, F.L., G.F.; methodology, F.L., G.F.; software, A.F., R.M., F.Q.; investigation, F.T.; data curation, F.T., N.S., A.K., H.S., and E.S. and F.M.P.F.; writing—original draft preparation, F.L., G.F., A.F., R.M., and F.Q.; writing—review and editing, F.L., G.F.; supervision, M.R. and M.M; project administration, G.F.; funding acquisition, F.T. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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