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Effect of a specific exercise strategy on strength and proprioception in volleyball players with infraspinatus muscle atrophy

J. I. Salles^{1,2}  | J. M. Guimarães³ | G. M. Filho³ | D. Morrissey^{1,4}

¹Sports and Exercise Medicine, William Harvey Research Institute, Queen Mary University of London, London, UK

²Fédération Internationale de Volleyball (FIVB) Coach Commission, Lausanne, Switzerland

³Research Division, National Institute of Traumatology and Orthopedic (INTO), Rio de Janeiro, RJ, Brazil

⁴Physiotherapy Department, Barts Health NHS Trust, London, UK

Correspondence

José Inácio Salles, Sports and Exercise Medicine, William Harvey Research Institute, Queen Mary University of London, London, UK.
Email: joseinaciosalles@hotmail.com

Infraspinatus muscle atrophy is common in professional volleyball players, but it is unclear whether commonly observed strength and proprioception deficits can be reversed with training. Fifty-four participants were recruited into an infraspinatus atrophy group (IAG, $n = 18$) and a non-atrophy group (NAG, $n = 18$) of elite volleyballers plus a healthy non-athletic control group (CG, $n = 18$). IAG were trained with a progressive, specific shoulder external rotator strengthening routine for 32 sessions over 8 weeks. Shoulder external rotation peak torque (SERPT) and threshold to detect passive movement (TTDPM) and joint position sense (JPS) were measured before and after the intervention. At baseline, no significant difference was detected in strength or proprioception between the injured and control groups, but the normal athletes were stronger and had better proprioception than either IAG or CG ($P < .001$). IAG ($d = 2.78$) and NAG ($d = 0.442$) improved strength significantly after training. IAG improved TTDPM and JPS ($P < .001$, $d = -0.719$ and -2.942 , respectively) but were still worse than NAG ($P < .001$). Elite volleyball players with Infraspinatus muscle atrophy have strength and proprioception deficits which can be improved by a specific exercise program to normal but not elite athlete control levels.

KEYWORDS

infraspinatus atrophy, isokinetic dynamometer, joint position sense, proprioception, strength training, threshold to detect passive movement, volleyball

1 | INTRODUCTION

Shoulder injuries are common in the high level overhead athlete,¹ particularly where there are repetitive high force overhead actions or direct contact. There are many potential nerve injuries seen about the shoulder in athletes, including suprascapular nerve dysfunction.^{2,3} Atrophy of the infraspinatus muscle is a common pathology in professional volleyball players and has been clinically recognized as corresponding to a suprascapular nerve palsy at a distal level.⁴⁻⁶ Studies on volleyball players report infraspinatus atrophy (Figure 1) in up to ~1/3 of elite players^{7,8}, with this high incidence implicating volleyball-specific aspects in injury pathogenesis.⁹ Infraspinatus atrophy has been associated with the level and duration of play, leading to the term *cumulative neuropraxia* as a suggested etiology.⁴ The extreme abduction with full

external rotation of the shoulder during the spike and service may lead to this neuropathy of the infraspinatus muscle and reduction of shoulder function,¹⁰ which in turn results in multiple observed deficits such as decreased shoulder external rotation strength,⁶ significantly increased threshold to detection of passive motion,¹¹ and deficits in dominant shoulder joint position sense.¹² Both proprioceptive and strength deficits could cause alterations in players' dominant arm function and predispose them to acute or overuse injuries.¹³

The athlete with suprascapular nerve palsy may be asymptomatic, therefore, the clinical relevance is as yet unclear, with most players reporting no pain during practice or competitions. The athlete complaining of weakness of external shoulder rotation can, however, progress to posterior shoulder subluxation due to infraspinatus strength deficit.² It is unclear whether these strength and proprioception deficits can be

reversed with training to promote adaptations of teres minor and posterior deltoid as suggested by Ferreti et al.¹⁴ We aimed to evaluate a specific, evidence-based exercise strategy designed to restore glenohumeral external rotation strength and improve proprioceptive performance. Specifically, we tested

the null hypothesis that a progressive exercise strategy targeting the posterior deltoid, supraspinatus, and teres minor would not improve shoulder strength or proprioception in volleyball athletes having infraspinatus muscle atrophy (Figure 1).

2 | MATERIALS AND METHODS

2.1 | Subjects

A total of 54 participants were included in this study, with 18 in each of three groups. Thirty-six subjects were professional volleyball players without shoulder pain, with half having been diagnosed with evident infraspinatus atrophy on clinical examination in the dominant shoulder. The clinical findings were confirmed by magnetic resonance imaging (MRI) evidence of diffuse fatty infiltration equal or greater than 2, graded according to Goutallier 5-point grading scale,^{15–17} therefore signalling approximately 50% atrophy, without other associated pathology in the infraspinatus atrophy group (IAG). The non-atrophy group (NAG) had no current pathology or neuromuscular disease in the dominant shoulder, while the control group was formed by healthy and non-athletic subjects without involvement in systematic training. Demographic data are displayed in Table 1. The study was approved by the local ethics committee, and participants provided informed consent prior to entering the study.

2.2 | PROCEDURES

2.2.1 | Infraspinatus muscle atrophy

The amount of fatty degeneration was graded according to Goutallier 5-point grading scale;^{15–17} grade 0 = no fatty deposits, grade 1 = some fatty streaks, grade 2 = less fat than muscle, grade 3 = as much fat as muscle, and grade 4 = more fat than muscle.^{15–17}

2.2.2 | Muscular strength

All strength testing procedures were applied on the dominant upper limb and performed on an isokinetic dynamometer (HUMAC NORM, CSMI, U.S.A.). The concentric shoulder external rotation peak torque (SERPT) was measured by means of five maximal contraction repetitions at a speed of 60°/s, using the same procedures as Kuhlmann et al¹⁸ who reported excellent reliability with intra-class correlation

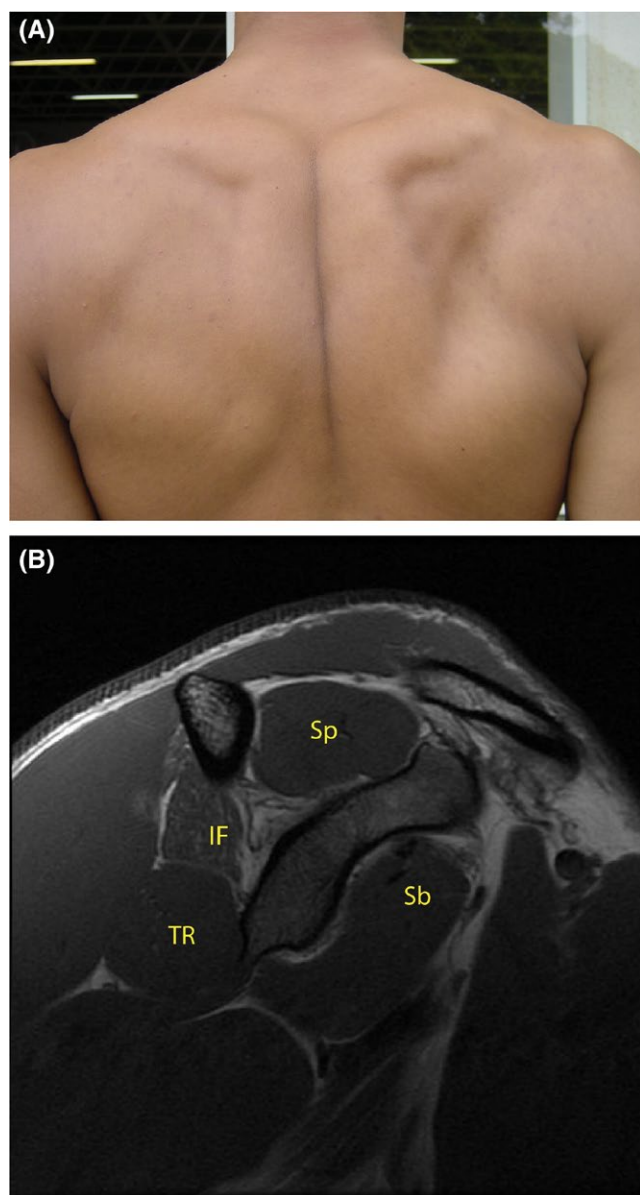


FIGURE 1 A, A photograph to demonstrate infraspinatus muscle atrophy in one player and B, Magnetic resonance imaging scan of a shoulder showing diffuse fatty infiltration stage II^{15–17} and atrophy of the infraspinatus muscle. IF, infraspinatus; Sb, subscapularis; Sp, supraspinatus; TR, teres minor

	Atrophy n:18	Normal n:18	Control n:18	P-value
Age (y)	26 ± 4.6	27 ± 4.9	28 ± 6.3	.421
Weight (kg)	84.9 ± 9.4	86.1 ± 7.8	82.3 ± 6.7	.363
Height (m)	195.8 ± 7.2	195.8 ± 5.7	180.7 ± 7.4**	**<.001

TABLE 1 Demographic data (mean ± SD) of differences between groups tested by one-way ANOVA. ** (significantly difference)

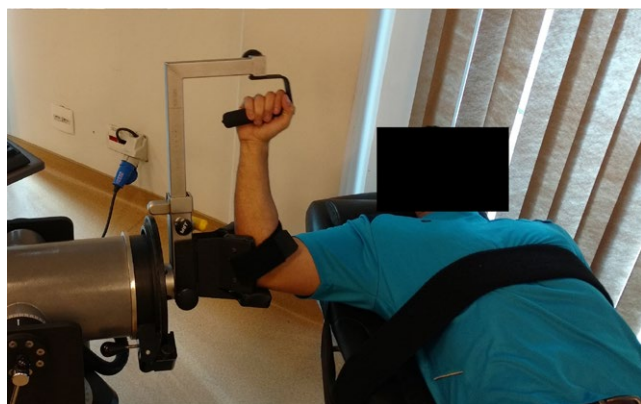


FIGURE 2 Shoulder joint position sense test

coefficients of 0.94 in healthy volunteers¹⁹. The participant was positioned in prone lying with the shoulder abducted and elbow flexed, both to 90° and the forearm neutral. After familiarization with the equipment and procedures, participants initiated the warm-up through five sub-maximal repetitions. Only the dominant arm of participants was evaluated with the highest instantaneous value found characterized as peak torque and stored for further analysis.

2.2.3 | Time to detect passive movement

To assess internal rotation time to detect passive movement (TTDPM) a custom made motor-driven proprioception testing device was used, as previously used and described in detail elsewhere.¹⁸ Briefly, the device provides shoulder internal movement passively with 0.4°/s velocity. The TTDPM was applied only on the dominant upper limb. The participants were instructed to immediately press a hand-held switch when shoulder movement was detected. TTDPM was measured by the time lapse between motor movement start and button press. The mean of three trials was calculated and proprioception acuity measured as the absolute error (AE).

2.2.4 | Joint position sense

Joint position sense (JPS) was measured using the isokinetic dynamometer with the subject following the same position described to SERPT (Figure 2). For the execution of joint position

reproduction test,¹⁸ the voluntary internal rotation movements from 0° until 45° from the starting position was chosen as analogous to the direction of player arm movement during the follow-through phase of spiking. The maximum external rotation angle was measured individually and established as the initial position (0°). The 45° position was maintained for 5 seconds to enable participants to experience their target joint position. The participant then attempted to reproduce the position. A total of three attempts were made. Variations of $\pm 5^\circ$ were allowed for the position experienced, if this margin was exceeded the attempt was discarded and a new attempt was made. The positioning of the subject was the same as previously described to SERPT. All participants were blindfolded to not benefit from visual feedback. The individual error was calculated by subtracting the position reproduced from the experienced position. Proprioceptive acuity was established through the calculation of the absolute error (AE), calculated by the mean value of the individual differences. Previous research has found this technique to be an accurate and reliable method of measuring shoulder (Figure 2) joint position sense.^{19,20}

2.3 | Strength training program

The strength training program was conducted at the Brazilian National Volleyball Training Center and sought to exert as much control as possible on resistance exercise parameters based on mechano-biological descriptors.²¹ The players of NAG and IAG performed the normal strength training routine consisting of basic exercises for the upper and lower limbs. The IAG in addition was instructed to perform a specific exercise program. The program applied only to the dominant side consisted of two sets of three different exercises during 8 weeks, four times a week (32 sessions). The exercises were: supraspinatus fly (Figure 3A), shoulder external rotation (Figure 3B), and Lying “L” Fly (Figure 3C). The intensity of exercises was individually adjusted and progressed with increasing external load by using free weights to 8-12 repetitions maximum (RM). The program started with the athletes performing the three exercises eccentrically with help until be able to perform concentrically without help. The CG subjects did not participate in any kind of intervention during the experimental period.



FIGURE 3 The exercises: A, supraspinatus fly; B, shoulder external rotation, C, Lying “L” Fly

TABLE 2 Pre- to Post-strength training intervention values of SERPT, TTDPM, and JPS

Group	SERPT (Nm)			AE TTDPM (s)			AE JPS (degrees)		
	Mean $\pm$ SD		<i>d</i>	Mean $\pm$ SD		<i>d</i>	Mean $\pm$ SD		<i>d</i>
	Pre	Post	Effect Size	Pre	Post	Effect Size	Pre	Post	Effect Size
IAG	37.8 $\pm$ 3.70	47.8 $\pm$ 3.47 ^{bc}	2.782 ^d	4.6 $\pm$ 1.38	3.7 $\pm$ 1.23 ^{bc}	-0.719	4.48 $\pm$ 0.48	3.12 $\pm$ 0.33 ^{bc}	-2.942 ^d
NAG	49.2 $\pm$ 5.04 ^a	51.3 $\pm$ 4.60	0.442	2.2 $\pm$ 0.58 ^a	1.9 $\pm$ 0.62 ^b	-0.316	1.98 $\pm$ 0.44 ^a	1.93 $\pm$ 0.48 ^b	-0.117
CG	38.3 $\pm$ 7.80	38.1 $\pm$ 7.77 ^{bc}	-0.029	4.8 $\pm$ 1.32	4.7 $\pm$ 1.48 ^b	-0.044	4.57 $\pm$ 0.79	4.59 $\pm$ 0.73 ^b	0.022

AE, absolute error; CG, control group; IAG, atrophy group; JPS, joint position sense; NAG, non atrophy group; Nm, Newton metre; S, seconds; SERPT, shoulder external rotation peak torque; TTDPM, threshold to detection of passive motion.

^asignificantly different between groups in pre-training period, $P < .001$.

^bsignificantly different between groups in post-training period, $P < .001$. JPS: IAG and CG ($P = .023$) and $P < .001$ for others comparisons.

^csignificantly different between pre-training and post-training by group, SERPT: IAG $P < .001$ and NAG $P = .004$; others $P < .001$.

^dlarge effect size.

2.4 | Statistical analysis

Measurement reliability was assessed by testing the CG at the equivalent of baseline and end of treatment for the intervention group. The Shapiro Wilk test showed all variables to be normally distributed (all $P > .05$). To evaluate demographic data (age, weight, and height) a one-way analysis of variance was used with a post-hoc Bonferroni comparison. To ensure measurement reliability intraclass correlation coefficients (ICC) were conducted for all CG data. Firstly, a two-way repeated measure analysis of variance (ANOVA) (measurement point [pre- and post-training] $\times$ groups [IAG, NAG and CG]) was used to identify the main effects in proprioception and strength variables. The repeated measures ANOVA were tested for sphericity and the Greenhouse-Geisser correction applied where necessary. The Bonferroni post-hoc test for pairwise comparison was applied. To define the magnitude of change after training intervention, an effect size (ES) was calculated by means of Cohen's formula²² and classified as proposed by Rhea.²³ All calculations were conducted through the software SPSS (IBM SPSS Inc., version 19, Chicago, IL, U.S.A.) and all graphs were produced with Graphpad Prism (GraphPad Software Inc, Version 5, La Jolla, CA, U.S.A.). The default significance level was set at 0.05.

3 | RESULTS

Diagnostically, seven athletes were graded at level 2 and eleven had level 3 fatty degeneration of the infraspinatus muscle.¹⁵⁻¹⁷ Analysis of demographic data demonstrated significantly difference only in CG where the height was less than both volleyball players groups ($P < .001$). Excellent measurement reliability was observed with ICC values of 0.97, 0.90, and 0.93 for SERPT, TTDPM, and JPS, respectively, in the CG. We found significant main effects for moment and groups, and for their interaction in SERPT ($F = 229.019$, $P < .001$), TTDPM ($F = 12.390$, $P < .001$), and JPS ($F = 50.296$, $P < .001$). At pre-training, IAG and CG did not show inter-group differences in the SERPT but both groups demonstrated lower shoulder external rotation strength when compared to NAG ($P < .001$) (Table 2). At baseline, no significant difference was detected on TTDPM and JPS (Table 2) between IAG and CG. The NAG demonstrated a significantly higher performance than IAG and CG ($P < .001$) for both proprioceptive measures. After training IAG and NAG improved strength significantly ($P < .001$ and $P = .004$, respectively) (Table 2). Only IAG improved both proprioceptive acuities after the training period ($P < .001$), although still worse than NAG ($P < .001$) (Table 2). A large effect size for SERPT, TTDPM, and JPS in IAG is shown in Table 2 and Figure 4, respectively. A small effect size is observed for SERPT in NAG (Table 2, Figure 4).

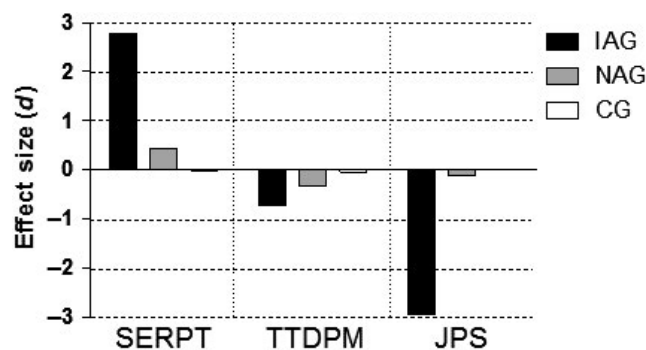


FIGURE 4 Effect Size for changes after intervention. CG, control group; IAG, atrophy group; JPS, joint position sense; NAG, Non atrophy group; SERPT, shoulder external rotation peak torque; TTDP, time to detect passive motion

4 | DISCUSSION

Volleyball players with infraspinatus muscle atrophy experience significantly greater improvements in shoulder strength and proprioception after a specific exercise strategy. Before the exercise intervention, SERPT revealed a significant weakness in the group of players with infraspinatus muscle atrophy. This finding is in agreement with the results of Ferretti et al.²⁴ and Holzgraefe et al.⁷ who both observed an external rotation strength deficit in the affected shoulder with clinical methods. In our study, NAG demonstrated better performance in TTDP and JPS in relation to the control group. This result corresponds to previous work suggesting that exercise and sport activities could have an effect on proprioception.^{18,20} However, in the pre-intervention period, no difference was observed between the CG and the IAG in the TTDP and JPS, which demonstrates the strong impact of this lesion on proprioception in volleyball players. Additionally, the significant deficit was also observed in TTDP and JPS of the IAG when compared to the NAG in the pre-intervention period. Possibly, it can be explained by the fact that the sensory branches of the suprascapular nerve reduce the efficiency to inform the parietal cortex about movement onset at the glenohumeral joint. This hypothesis is based on evoked potentials recorded in the somatosensory cortex demonstrating the presence of an afferent neural pathway originating in the glenohumeral joint.²⁵ The proprioception tests in the present study were performed from external to internal rotation resulting in mechanical stress of the posterior shoulder capsule. This strategy was due to the fact that the sensory branches of the suprascapular nerve after passing the suprascapular notch run inferomedially toward the posterior shoulder capsule.²⁶ The relationship between nerve compression, anatomy and pathology is difficult to determine because players typically do not report pain yet clearly have significant proprioceptive loss, suggesting that nociceptors and superficial sensory nerve fibers arise before the spinoglenoid notch and are unaffected. Ferretti et al.²⁷ recognize the

spinoglenoid notch as the point of entrapment. Players with infraspinatus atrophy did not report compromised sporting performance.^{1,6,11,27,28} However, proprioceptive deficit may be an indicator of joint instability and risk of other comorbidities.^{6,29–31} The functional stability of the shoulder can be impaired when there is impaired information quality from mechanoreceptors at different levels of the motor control.

After 8 weeks no significant changes were observed in the SERPT, TTDP, and JPS indices in the CG indicating that time alone, or repeated testing was not responsible for the observed differences in the intervention group. In addition, evaluation of the performance parameters observed in the present study demonstrated good reliability with indices of 0.97, 0.90, and 0.93 for SERPT, TTDP, and JPS, respectively. The specific strength training program for SERPT was sufficient to significantly increase in the IAG. Although the NAG also showed a significant increase in SERPT, attributed to the training common to all players who participated in this research, the effect size was small while it was large in IAG (Table 2). No difference was found in SERPT between volleyball player groups after the training period, indicating reversal of the pre-training deficit. High-performance athletes are typically close to the absolute level of conditioning in sports-relevant skills and abilities, including strength. However, after the intervention, the large effect size of SERPT change represents how much the IAG players had improved, while the high magnitude of the initial deficit indicates how markedly affected shoulder strength was.

The IAG showed a significant change in proprioceptive tests after the specific strength program. The large effect size (Table 2) for post-intervention proprioception change in IAG contrasts with the unchanged NAG group, therefore, suggesting that the players without pathology already had optimal proprioception and the change was not simply due to altered training but also the compromised state of those with infraspinatus atrophy. Although some authors have described the effects of muscle strengthening on proprioception^{32,33} the mechanisms should be better understood. The sensory branch distribution of the suprascapular nerve that reaches the posterior shoulder capsule^{34,35} and mechanoreceptors localized in the capsule tissue seem to be part of a physiological feedback mechanism³⁵ that supports the proprioceptive tests applied in this study due to the maximum strains on the glenohumeral joint posterior capsule observed during internal rotation.³⁶ This suggests that the athletes with suprascapular nerve palsy may show a delay in the detection of passive motion from external to internal rotation when compared to their peers without nerve impairment, kinematically relevant to the follow through phase of spiking. The improvement of proprioception may be compensatory rather than reflective of nerve recovery, a factor made more likely by our anecdotal observation that the strength change is likely due to teres minor hypertrophy rather than infraspinatus recovery.

The strength training directly affects the functional capacity of the dynamic stabilizers of the glenohumeral joint.³³

The significant improvement in shoulder proprioception seen in the specific exercise group was a response from the strength program that supports the current clinical practice of strength training to address proprioception deficits.¹⁸ Deficits in static and dynamic stability were observed by Contemori and Biscarini¹³ in professional volleyball players with infraspinatus muscle atrophy. In addition to greater joint stability, the strength training intervention applied in IAG may favor the efficiency of mechanoreceptors in the posterior capsule increasing the performance in passive motion detection. The possible adaptation of teres minor and posterior deltoid in players with infraspinatus atrophy, suggested by Ferretti et al¹⁴ and Safran et al,² can increase muscle spindle efficiency to detect changes in the rate of stretching of these muscles during voluntary joint position sense test.^{20,37} Besides sending sensory information, muscle spindles also receive efferent motor connections through gamma motoneurons that activate regulatory system sensitivity during voluntary muscle contraction.³⁸ Thus, the neuromuscular mechanism responsible to improve proprioception in our research may be attributable to improved muscle spindle sensitivity after strength training, resulting in better shoulder position sense. Interestingly, athletes often reported the shoulder felt more stable and secure, another anecdotal observation suitable for follow-up in future work.

The study also has some limitations. As all surveys conducted with athletes in regular training, the volume and intensity of the technical elements of volleyball are not strictly controlled. The long-term benefits of treating this pathology (injury prevention, sport performance) were not assessed. We did not have electrophysiological evidence of suprascapular nerve injury and MRI was not applied after intervention to compare with baseline so it can not be determined if muscle recovery took place or if other muscles compensated for the lack of infraspinatus. The good orientation and control of the strength training program common to all athletes and the specific exercise intervention for the group of athletes with infraspinatus atrophy were particular strengths of the present study. Further research is warranted to explore the morphological and biomechanical adaptations of programs to strengthen the external rotators of the volleyball player's shoulder with infraspinatus muscle atrophy in order to better understand therapeutic mechanisms and further improve treatment outcomes.

5 | CONCLUSION

The study demonstrated that the proposed strengthening exercise program can be a useful therapeutic tool to improve proprioception and external rotation strength of the shoulder in athletes with infraspinatus muscle atrophy. Therefore, these findings may be helpful for sports science and medicine teams who aim to prevent subsequent shoulder injury

by improving strength and proprioception for athletes with isolated infraspinatus muscle atrophy.

6 | PERSPECTIVE

The particular repetitive mechanical stress performed by volleyball players predispose their dominant shoulder to infraspinatus muscle atrophy,^{12,28,39,40} which is strongly associated with reduced proprioceptive information^{11,12} and strength deficits.^{6,12} If untreated, these deficits could lead to further comorbidities in this complex joint. The study findings show that athletes with infraspinatus muscle atrophy can partially reverse strength and proprioception deficits through short- to medium-term specific strength training. We therefore have a rehabilitation strategy with proven, albeit partial, efficacy. Developing prevention strategies is important, with monitoring of proprioception and strength being potential early indicators of neural compromise which would allow early intervention.

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ORCID

J. I. Salles  <https://orcid.org/0000-0003-4173-0352>

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