

EFFECTS OF CALF COMPRESSION GARMENTS ON NON-LINEAR UNDERWATER DISPLACEMENT IN ELITE UNDERWATER RUGBY PLAYERS: A CROSSOVER STUDY

EFFECTOS DE LAS PRENDAS DE COMPRESIÓN EN PANTORRILLA SOBRE EL DESPLAZAMIENTO SUBACUÁTICO NO LINEAL EN JUGADORES ÉLITE DE RUGBY SUBACUÁTICO: ESTUDIO CRUZADO

Samuel José Gaviria Alzate¹ , Wilder Geovany Valencia-Sánchez² 

¹ Facultad de Educación y Ciencias Sociales, Institución Universitaria Tecnológico de Antioquia, Medellín, Colombia

² Instituto Universitario de Educación Física y Deporte, Universidad de Antioquia UDEA, Medellín, Colombia

Correspondence:

Samuel José Gaviria Alzate, samuel.gaviria@tdea.edu.co

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Abstract

This study explored the effects of calf compression garments (CCG) on non-linear underwater movement in elite underwater rugby players. Given the sport's demand for agility, fast direction changes, and precise body control, any improvement can offer a competitive edge. Five elite athletes with over nine years of average experience completed five repetitions of a Change of Direction Speed (CDS) test under two conditions: with CCG and without them (WCCG). The study followed a crossover design over seven days, allowing each participant to act as their own control. Results consistently showed better performance with CCG, especially during the fourth and fifth test repetitions. Mean times improved from 7.27 to 6.89 seconds and from 7.20 to 6.90 seconds, respectively. The overall average time was faster with compression (7.01 ± 0.42 s) compared with the condition without compression (7.18 ± 0.43 s). Statistical analysis confirmed a significant difference ($t(24) = 2.41$, $p = .024$), with a moderate effect size (Cohen's $d = 0.48$). Performance improved by 2.40%, particularly in later repetitions, suggesting a possible fatigue-buffering effect. These findings indicate that CCG may enhance agility-based performance in aquatic sports. Further research should investigate the underlying physiological mechanisms and broader applications in similar environments.

Keywords: Calf compression garments, athletic performance, non-linear displacement, water sports, crossover studies.

Resumen

Este estudio exploró los efectos de las prendas de compresión en pantorrilla sobre el desplazamiento subacuático no lineal en jugadores élite de rugby subacuático. Dado que este deporte exige agilidad, cambios rápidos de dirección y control corporal preciso, cualquier mejora en el rendimiento puede representar una ventaja competitiva. Cinco atletas élite, con una experiencia promedio superior a nueve años, completaron cinco repeticiones de una prueba de velocidad con cambio de dirección bajo dos condiciones: con prendas de compresión en pantorrilla y sin prendas de compresión. El estudio siguió un diseño cruzado durante siete días, permitiendo que cada participante actuara como su propio control. Los resultados mostraron consistentemente un mejor rendimiento con el uso de las prendas de compresión, especialmente durante la cuarta y quinta repetición de la prueba. Los tiempos medios mejoraron de 7,27 a 6,89 segundos y de 7,20 a 6,90 segundos, respectivamente. El tiempo promedio global fue menor con compresión en comparación con la condición sin compresión: $7,01 \pm 0,42$ s frente a $7,18 \pm 0,43$ s. El análisis estadístico confirmó una diferencia significativa, $t(24) = 2,41$, $p = .024$, con un tamaño del efecto moderado, d de Cohen = 0,48. El rendimiento mejoró un 2,40%, particularmente en las repeticiones finales, lo que sugiere un posible efecto atenuador de la fatiga. Estos hallazgos indican que las prendas de compresión en pantorrilla pueden mejorar el rendimiento basado en la agilidad en deportes acuáticos. Futuras investigaciones deberían examinar los mecanismos fisiológicos subyacentes y sus posibles aplicaciones en entornos deportivos similares.

Palabras clave: Prendas de compresión en pantorrilla, rendimiento deportivo, desplazamiento no lineal, deportes acuáticos, estudios cruzados.

Introduction

In elite sport, technological innovation is frequently used to reduce small performance gaps that may be decisive in competition. Advances in competitive swimming suits, hydrodynamic equipment and training-monitoring systems illustrate how material design and applied sport science can influence performance contexts (Morales et al., 2019; Ravé et al., 2020; Rogowski et al., 2006). Within this broader technological landscape, compression garments have become a widely used individual aid in training and competition. Although they originated in clinical contexts to support venous return and manage lower-limb circulation, their use in sport has expanded because of their potential influence on recovery, perceived exertion, muscle support and repeated-effort performance (Brown et al., 2017; MacRae et al., 2011).

Compression garments are elastic garments designed to apply mechanical pressure to specific body regions. Their possible effects are commonly associated with graduated pressure, improved venous return, altered muscle oxygenation, reduced muscle oscillation and enhanced proprioceptive feedback (Born et al., 2013; Horiuchi et al., 2018; MacRae et al., 2011). Garment construction is therefore relevant: compression level, fit, length, fibre composition and manufacturing method may alter the pressure applied to the limb (Hill et al., 2015). Commercial lower-limb garments are typically produced with synthetic elastic fibres, such as elastane or spandex combined with polyamide or nylon, to maintain stretch, fit and durability during exercise. However, commercially available garments may exert different pressures depending on brand, size and model, which partly explains the variability reported in the literature (Hill et al., 2015).

Evidence regarding compression garments in sport remains mixed and context dependent. Some studies have reported improved recovery markers, reduced muscle soreness or better maintenance of subsequent performance after demanding exercise (Brown et al., 2017; Goto & Morishima, 2014; Hill et al., 2014; Jakeman et al., 2010; Kraemer et al., 2010). In performance contexts, findings have also varied across exercise modes. For example, lower-body compression garments have been associated with improved subsequent cycling time-trial performance and enhanced anaerobic outputs in basketball players during Wingate testing (Ballmann et al., 2019; De Glanville & Hamlin, 2012). Conversely, systematic reviews and sport-specific studies have indicated small, inconsistent or non-significant effects on some high-intensity and running-related outcomes (Da Silva et al., 2018; Duffield & Portus, 2007; Wang et al., 2025). Thus, the potential usefulness of compression garments appears to depend on the task, population, garment characteristics and whether the outcome reflects acute performance, repeated-effort tolerance or recovery.

Aquatic team sports provide a distinctive context in which the effects of compression garments remain insufficiently studied. Underwater rugby requires repeated apnoeic efforts, rapid submersions, body contact, acceleration, deceleration and non-linear underwater displacement while athletes manage buoyancy, drag and limited breathing opportunities. Unlike linear swimming tasks, underwater rugby involves frequent changes of direction, turns around opponents or spatial references, and short high-intensity actions performed under hypoxic and hydrodynamic constraints. These demands place substantial stress on the lower limbs because fins, kicks and body orientation are central to propulsion and manoeuvrability. Consequently, calf compression garments could theoretically influence underwater change-of-direction performance by supporting the calf musculature, improving proprioceptive sensation or attenuating fatigue-related decrements across repeated efforts.

Despite extensive research on compression garments in land-based sports and recovery contexts, their acute effect on repeated non-linear underwater displacement in elite underwater rugby players remains unclear. This gap is practically relevant because underwater rugby athletes frequently perform repeated bouts in which small changes in displacement time may affect ball possession, defensive recovery and tactical positioning. Therefore, the aim of this study was to evaluate the influence of calf compression garments on non-linear underwater displacement performance in elite underwater rugby players.

Materials and Methods

Design

This exploratory randomised crossover study compared two experimental conditions: use of calf compression garments (CCG) and no calf compression garments (WCCG). A crossover design was selected because each participant could act as their own control, which is appropriate when the exposure can be withdrawn and potential carryover effects are minimised through adequate separation between conditions (Senn, 2002; Wellek & Blettner, 2012).

Participants performed the CDS test with and without compression garments across two sessions separated by a seven-day washout period. The seven-day interval was used to minimise acute residual effects related to fatigue, recovery or familiarity with the preceding condition. The order of conditions was randomised to reduce order-related bias.

The study protocol received ethical approval from the Research Ethics Committee of Universidad de San Buenaventura, Medellín campus, in June 2024, and was conducted in accordance with the principles of the Declaration of Helsinki.

Sample

The selection method for the rugby players was non-probabilistic and based on convenience and feasibility (Etikan, 2016). The sample consisted of five adult underwater rugby players ($n = 5$) from a Swimming League. Participants were 29.4 ± 2.3 years old, had 9.80 ± 10.23 years of underwater rugby experience, and had at least two years of previous practice in the sport. None of the participants reported musculoskeletal issues before testing.

Procedures

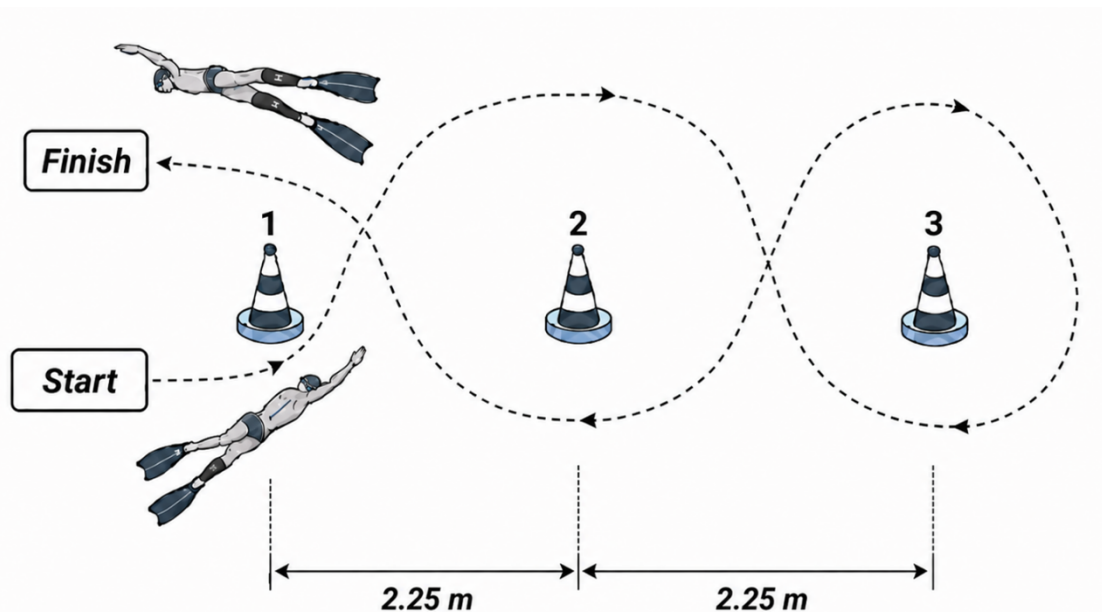
The non-linear underwater displacement of participants was evaluated using the CDS test, a validated protocol for assessing underwater agility and performance (Gaviria Alzate et al., 2021). This test involves performing a predefined underwater course with directional changes, assessing time and efficiency of movement (Table 1) (Figure 1).

Table 1

Description of the Non-linear Underwater Displacement Protocol

Phase	Description	Details
Warm-up (Series 1)	6 laps without fins: 12.5 m dominant kick + 12.5 m freestyle	50% intensity
Warm-up (Series 2)	6 laps with fins: 12.5 m dominant kick + 12.5 m full freestyle	50% intensity
Warm-up (Series 3)	4 sprints with fins: each sprint is 12.5 m, dominant kick	All out intensity, 30-second rest between sprints
Rest Periods	Participants rested for 90 seconds between series	
CDS Test	The test is performed in apnea and with fins. The athlete avoids three floating objects in a zigzag pattern at a depth of 4 meters.	The time is recorded from the start until the athlete touches the endpoint.
Additional Details	The floating objects are spaced 2.25 meters apart (Figure 1).	
Actions Invalidating Test	Using any surface to generate additional propulsion. Failing to complete the test. Touching any of the floating objects with the body or fins during displacement.	

Note. This table outlines the procedure for the warm-up, the main CDS test, and conditions that invalidate the results (Gaviria Alzate et al., 2021).

Figure 1*Underwater Direction Change Test (CDS)*

Note. Start and finish labels were checked and corrected. Adapted from Gaviria Alzate et al. (2021).

Each participant completed the test a total of ten times, performing five repetitions with compression garments applied to the calf area and five without. The order of conditions was randomised to minimise potential biases. The tests were conducted in two separate sessions, spaced seven days apart, to minimise the effects of fatigue on the results. The participants were in the competitive preparation phase of the season and maintained their regular training schedules, which included two in-water sessions and two strength sessions per week. The tests were conducted on consecutive Saturdays at 3:00 PM to align with their typical training hours.

The compression condition used new calf compression garments supplied by Hilo Socks Colombia (Medellín, Colombia; model HSPAN001). The garments were calf-only graduated compression sleeves selected according to manufacturer sizing guidelines and applied bilaterally before the CDS repetitions. The manufacturer-reported compression range was 15-20 mmHg. The garment extended from below the knee to above the ankle, covering the lower leg exclusively. The material composition was described on the product label as a synthetic elastic textile blend; however, the exact fibre percentages were not available in the retained product documentation.

The tests were conducted under controlled conditions at an outdoor swimming facility in Medellín, Colombia, situated at an altitude of approximately 1,500 metres above sea level. The pool had a depth of 5 metres, a length of 25 metres, and a width of 20 metres. The water temperature was maintained at an average of 27°C ($\pm 1^\circ\text{C}$), and the ambient air temperature ranged between 25°C and 28°C.

Participants were instructed to be ready at the pool edge and began the test following a visual signal from the evaluators. The starting point was the pool wall, and the finish line was marked by a buoy located 10 metres away. The evaluators used underwater hand signals to indicate the start of each attempt, and the time measurement began when the participant's head was fully submerged and ended when they crossed the buoy line. To ensure the two-minute rest intervals were consistent, evaluators used a digital stopwatch (Casio HS-80TW, Japan), starting the timer as soon as the participant resurfaced and stopping it at the next submersion.

The times were recorded by two independent evaluators with more than five years of experience in underwater rugby, both holding undergraduate degrees in sports science. They remained submerged during the test and used synchronised digital stopwatches. Additionally, all attempts were recorded using a GoPro Hero 5 camera (GoPro Inc., San Mateo, CA, USA) at 120 fps, allowing for subsequent reviews to ensure measurement accuracy.

Statistical Analysis

Normality was assessed using the Shapiro-Wilk test applied to the paired differences. Results are presented as mean and standard deviation (*SD*). Paired-samples Student's *t* tests were used to compare the two conditions (CCG and WCCG) for each repetition and for the overall repeated-observation comparison. Effect sizes were reported as Cohen's *d*. Statistical analyses were performed using Jamovi software (version 2.3.28). Visual Studio Code was used for data visualisation.

Results

Five adult elite underwater rugby players completed all assessments. Participants had 9.80 ± 10.23 years of underwater rugby experience; this value refers to years of practice in the sport, not chronological age. Chronological age was 29.4 ± 2.3 years old. Participants completed the Change of Direction Speed (CDS) test on five separate occasions under both conditions, resulting in 25 observations per condition. Body mass was 77.00 ± 17.00 kg and height was 160.40 ± 6.73 cm. All Shapiro-Wilk tests were non-significant.

Descriptive Analysis

Table 2 presents the means, standard deviations (*SD*), minimum and maximum values, percentage change, and the results of the Shapiro-Wilk normality test for five repetitions of the CDS test under conditions with compression garments (CCG) and without compression garments (WCCG).

Table 2

Comparison of Performance With and Without Calf Compression Garments Across Repetitions

Test Condition	<i>N</i>	Mean (s)	<i>SD</i>	Minimum	Maximum	% Change
WCCG 1	5	7.16	0.44	6.41	7.55	-1.68%
CCG 1		7.04	0.63	6.00	7.67	
WCCG 2	5	7.13	0.42	6.58	7.69	-0.56%
CCG 2		7.09	0.46	6.36	7.54	
WCCG 3	5	7.14	0.32	6.74	7.61	-0.42%
CCG 3		7.11	0.54	6.33	7.64	
WCCG 4	5	7.27	0.60	6.62	8.10	-5.23%
CCG 4		6.89	0.29	6.50	7.32	
WCCG 5	5	7.20	0.48	6.84	8.00	-4.17%
CCG 5		6.90	0.12	6.76	7.06	

Note. WCCG = without calf compression garments; CCG = with calf compression garments. Percentage change represents the relative improvement of CCG compared with WCCG in each repetition.

In the first repetition (WCCG 1 vs. CCG 1), the mean for the condition without compression garments was 7.16 ± 0.44 seconds, while the condition with compression garments showed a slightly lower mean of 7.04 ± 0.63 seconds, reflecting a percentage change of -1.68% in favour of compression garments.

In repetitions 2 and 3, minimal differences were observed between the two conditions. In WCCG 2, the mean was 7.13 ± 0.42 seconds compared to 7.09 ± 0.46 seconds in CCG 2, corresponding to a -0.56% change. Similarly, in WCCG 3, the values were 7.14 ± 0.32 seconds versus 7.11 ± 0.54 seconds for CCG 3, representing a -0.42% change.

From the fourth repetition (WCCG 4 vs. CCG 4) onwards, the difference between the conditions became more pronounced. WCCG 4 showed a higher mean of 7.27 ± 0.60 seconds, while CCG 4 demonstrated a lower mean of 6.89 ± 0.29 seconds, reflecting a percentage change of -5.23% in favour of compression garments.

In the fifth repetition (WCCG 5 vs. CCG 5), the difference between the two conditions persisted. WCCG 5 had a mean of 7.20 ± 0.48 seconds, whereas CCG 5 showed a lower mean of 6.90 ± 0.12 seconds, with a percentage change of -4.17%.

Regarding the comparison between test one and test five in both conditions, the group without compression garments exhibited a slight increase from 7.16 seconds in WCCG 1 to 7.20 seconds in WCCG 5, corresponding to a 0.04-second difference (0.56% increase). In contrast, the group with compression garments reported a decrease from 7.04 seconds in

CCG 1 to 6.90 seconds in CCG 5, representing a 0.14-second improvement (-1.99%). These results reinforce the potential role of compression garments in mitigating performance decrements associated with fatigue during repeated high-intensity underwater efforts.

Inferential Analysis

A comparison was made between the conditions with compression garments (CCG) and without compression garments (WCCG) across five repetitions, evaluating the mean differences and their significance (Table 3).

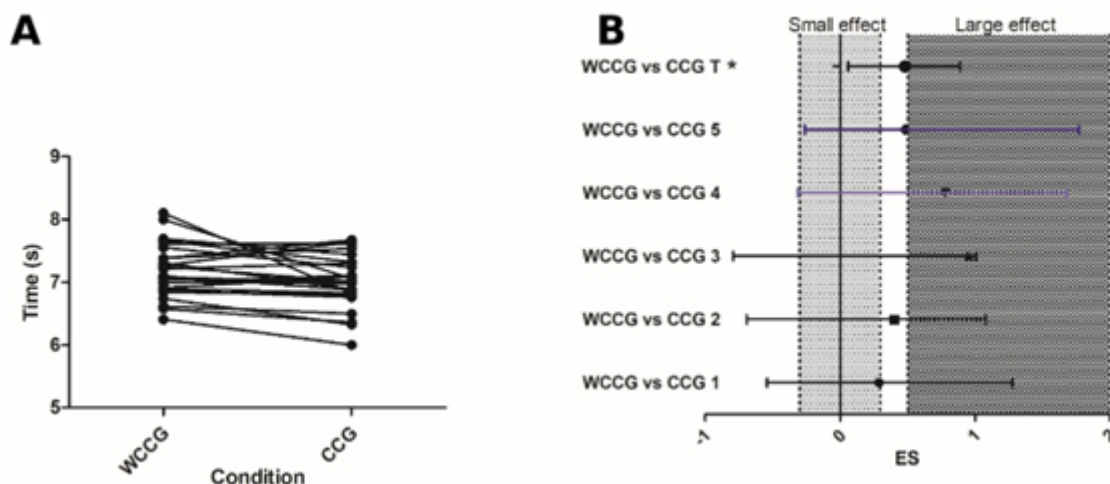
Table 3
Comparison of WCCG and CCG Conditions Using Paired-Samples t Tests

Test	Statistic t	df	p	Effect size (Cohen's d)	95% CI lower	95% CI upper
WCCG 1 vs CCG 1	0.88	4.00	.42	0.48	0.06	0.89
WCCG 2 vs CCG 2	0.46	4.00	.66	0.29	-0.54	1.28
WCCG 3 vs CCG 3	0.19	4.00	.85	0.40	-0.69	1.08
WCCG 4 vs CCG 4	1.59	4.00	.18	1.01	-0.79	0.95
WCCG 5 vs CCG 5	1.75	4.00	.15	0.78	-0.31	1.68
WCCG vs CCG*	2.41	24	.024	0.48	0.26	1.77

Note. WCCG = without calf compression garments; CCG = with calf compression garments.
*Statistically significant difference.

In the first two repetitions (WCCG 1 vs CCG 1 and WCCG 2 vs CCG 2), the mean differences were small, not statistically significant ($p > .05$), and the effect sizes were small-to-moderate (Cohen's $d = 0.48$ and 0.29 , respectively) (Figure 2). The 95% confidence intervals also indicated a lack of substantial differences between the two conditions.

Figure 2
CDS Test Performance and Effect-Size Estimates Under Calf-Compression and No-Compression Conditions



Note. Panel A shows participant-level paired performance times in the Change of Direction Speed (CDS) test under the no-compression condition and the calf-compression garment condition. Each line represents a paired observation. Panel B shows effect-size estimates for paired comparisons between conditions for each test repetition and for the overall comparison. Horizontal lines represent 95% confidence intervals. CCG = calf compression garments; WCCG = without calf compression garments; ES = effect size. The asterisk indicates a statistically significant overall comparison.

From the third repetition onwards, participants exhibited longer times under the condition without compression garments (WCCG). In repetitions three, four, and five, the mean differences increased, particularly in WCCG 4 vs CCG 4 and WCCG 5 vs CCG 5, where the differences were 0.37 and 0.30 seconds, respectively. Although these differences did not reach

statistical significance ($p > .05$), the effect sizes were larger in these later repetitions ($d = 1.01$ and 0.78), suggesting a more pronounced influence of compression garments on performance under repeated-effort conditions.

On average, participants demonstrated shorter times with the use of compression garments (7.01 ± 0.42 s) compared with the condition without compression garments (7.18 ± 0.43 s) across the five repetitions (Figure 2). This difference was statistically significant ($t(24) = 2.41, p = .024$), with a moderate effect size (Cohen's $d = 0.48$), corresponding to a percentage difference of 2.40%. The degrees of freedom ($df = 24$) were calculated by multiplying the number of participants ($n = 5$) by the number of paired observations per participant (five repetitions), reflecting the total number of repeated observations used in the paired t test.

Figure 2 presents a comparative analysis of performance times between conditions with and without compression garments across five repetitions of the CDS test. Panel A shows the mean performance times across repetitions, while Panel B shows the effect-size estimates for the paired comparisons with their 95% confidence intervals.

Discussion

This study aimed to evaluate the influence of calf compression garments on non-linear underwater displacement performance in elite underwater rugby players. From the third repetition onwards, trends were observed indicating that the subjects showed longer times in the condition without compression garments (WCCG). In repetitions three, four, and five, the mean differences increased significantly, especially in WCCG 4 vs. CCG 4 and WCCG 5 vs. CCG 5, where the differences were 0.37 and 0.30 seconds, respectively. Although these differences did not reach statistical significance ($p > .05$), the effect size grew substantially in these later repetitions (Cohen's $d = 0.71$ and 0.78), suggesting a relevant impact of fatigue under the non-compression condition. The confidence intervals for these cases included a wider range, suggesting greater variability in the results.

Although most evidence regarding the use of compression garments has focussed on post-exercise recovery, primarily to accelerate muscle damage repair and improve perceptual parameters (Querido et al., 2024), our study offers a novel perspective by evaluating the direct impact of these garments on non-linear underwater displacement performance in rugby players. The literature indicates that compression garments are commonly used during the post-match period to aid recovery over up to 72 hours (Querido et al., 2024), yet practical considerations such as comfort and potential effects on body temperature may influence their application. Our findings, which demonstrated significant improvements in displacement times with compression garment use, suggest that these garments may not only serve a recovery function but also enhance performance in specific conditions, likely through mechanisms such as improved blood circulation and reduced muscular fatigue. This dual functionality expands the potential applications of compression garments and opens new avenues for research into their strategic use not only for recovery but also for optimising performance during training or competition.

These findings align with previous research indicating that compression garments can mitigate fatigue-related performance decrements by enhancing circulation, reducing muscle oscillation, and improving proprioception during repeated high-intensity efforts (Born et al., 2013; MacRae et al., 2011). Additionally, studies on intermittent sports have reported similar trends, where athletes wearing compression garments exhibit better maintenance of movement efficiency and lower performance decline over successive repetitions (Dupuy et al., 2018). The underlying physiological mechanisms have been attributed to improved venous return, reduced muscle oscillation, and better muscle oxygenation (Da Silva et al., 2018; Goto & Morishima, 2014). However, research on this topic remains inconclusive, with some studies reporting mixed findings regarding their impact on performance and fatigue mitigation (Brown et al., 2017; J. Hill et al., 2014).

In this study, the observed performance differences became more pronounced in later repetitions, suggesting that compression garments may play a role in delaying the onset of fatigue. The lack of significant differences in the initial repetitions indicates that early-stage fatigue was not substantially affected by the garments. However, the progressive divergence observed from the fourth repetition onwards suggests that compression garments may help maintain performance under sustained effort. This could be particularly relevant in underwater rugby, where athletes perform repeated high-intensity efforts with short recovery intervals.

The potential benefits of compression garments can be explained through several physiological mechanisms. Compression has been shown to enhance venous return, facilitating oxygen and nutrient delivery to active muscles while

accelerating the removal of metabolic waste products (MacRae et al., 2011). Additionally, compression garments may reduce muscle oscillation, which could minimize muscle damage and improve proprioceptive feedback (Born et al., 2013; Brown et al., 2017). These factors may collectively contribute to better performance stability and reduced fatigue accumulation during repeated efforts.

However, the variability in the present findings highlights the need to consider the specific demands of underwater rugby and the individual responses of athletes. The non-linear underwater displacement task used in this study represents only a small fraction of the physiological demands encountered during a full match, where players are exposed to continuous changes in intensity, contact, and hypoxic conditions. Future research should incorporate more comprehensive performance assessments, including physiological markers such as muscle oxygen saturation, lactate accumulation, and heart rate variability, to better understand the impact of compression garments on underwater rugby performance.

Limitations

It is also important to acknowledge the limitations of the present study. Fatigue was inferred indirectly through performance decrements rather than measured directly through physiological markers. Additionally, the compression garments used in this study were new, with a manufacturer-reported compression range of 15-20 mmHg and were specifically designed for athletic use; however, the exact pressure applied to each athlete was not independently verified during testing. Future studies should consider evaluating the long-term effects of compression garments during match simulations and in combination with other recovery strategies. Furthermore, the potential for a Hawthorne effect, where participants modify their behaviour due to awareness of being observed, cannot be ruled out and should be addressed in future research designs.

Conclusion

In conclusion, while the findings of this study suggest that calf compression garments may help maintain performance during repeated underwater efforts, further research is required to confirm these effects and explore the underlying physiological mechanisms. Given the unique demands of underwater rugby, future studies should adopt sport-specific protocols and include a wider range of performance and recovery measures to provide more conclusive evidence on the efficacy of compression garments in underwater sports.

Practical Implications

Compression garments may be a valuable tool for enhancing performance and recovery in underwater rugby players. Athletes could benefit from incorporating them into their training routines, particularly for managing fatigue and supporting recovery during high-intensity training sessions or competitions. However, it is advisable that athletes seek guidance from sports science or medical professionals before integrating compression garments into their regimen to ensure their appropriate use and minimise any potential risks.

Ethics Committee Statement

The project received ethical approval from the local university's Research Ethics Committee in June 2024, following the principles outlined in the Declaration of Helsinki.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Author Contributions

All authors contributed significantly to the conceptualization, methodology, data collection, analysis, and writing of this manuscript. All authors have read and approved the final version of the article for publication.

Data Availability Statement

Data supporting these findings is available upon reasonable request to the corresponding author: samuel.gaviria@tdea.edu.co.

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