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PERSPECTIVE

Coastal rowing beach sprint, the new olympic discipline: sports engineering considerations

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Abstract
The inclusion of Coastal Rowing Beach Sprints in the 2028 Olympic program is reshaping the sport by mainstreaming racing in challenging and unpredictable open-water environments, characterized by waves, sharp turns, and constantly changing conditions. Despite its rapid growth in popularity, further systematic research on how to enhance performance, excitement and enjoyment while maintaining athlete safety remains limited. As a result, athletes, event organisers, equipment manufacturers, and governing bodies face a steep learning curve. This work highlights the key technical and safety aspects of the discipline that warrant further development and proposes conceptual solutions grounded in science and engineering. It also outlines a preliminary roadmap for future research aimed at advancing safety, performance, and the overall athlete and spectator experience in coastal rowing—an endeavour that demands collaboration between the sporting, scientific, and engineering communities.

Keywords Coastal rowing · Auxetic · Metamaterials · Safety · Personal protective equipment

1 Introduction

It's official: In October 2023 the International Olympic Committee (IOC) announced that the discipline of Coastal Rowing in Beach Sprint format will be part of the 2028 Los Angeles Summer Olympic Games [1, 2]. This "wild cousin" of classic rowing is a youthful discipline which brings with it the promise of a non-complex low-cost version of rowing that embraces beach culture and provides entertainment for the spectators. It is also claimed to promote universality, gender-equality and sustainability [3].

Coastal rowing in its modern format developed in France in the late 1980s and stems from an idea of Gerard D'Aboville. Coastal rowing races were originally organized as endurance races, typically over a six-kilometer distance. Beach Sprint races (*vide* Supplementary Information), shorter races which take place close to shore within sight of the spectators, are a more recent development and made their debut a decade ago as part of the 2015 Mediterranean Beach Games held in Italy. World Rowing Beach Sprint Finals (WRBSF) were first held in 2019 in Shenzhen, China and have continued to be held annually ever since. Since the 2023 event in Barletta, Italy, every edition has featured a para-rowing race where an athlete with a disability rows alongside an

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able-bodied rower of the opposite sex in a coastal double (C2×). This inclusion event became formalized in the 2025 edition of the World Rowing Rule Book, which specifies that the para rower needs to have a PR3-PI (physical impairment) classification. All this positively contributes to help reaching United Nations Sustainable Development Goals by ensuring gender equality (SDG 5), empowering women (SDG 5) and reducing inequalities (SDG 10) [4]. Despite the rapid rise in popularity of coastal rowing beach sprints in recent years, further research is required, particularly as the sport continues to evolve in ways that must balance the enjoyment of competition for both athletes and spectators with the need to safeguard athlete safety. The present work seeks to contribute to addressing this gap by drawing attention to the principal technical and safety considerations that warrant targeted development, and by setting out an initial roadmap for future research directions. The overarching aim is to advance safety, athletic performance, and the overall competitive and spectator experience in coastal rowing. Furthermore, this work proposes a series of conceptual solutions grounded in scientific and engineering principles, which may provide the impetus for further studies and innovations, thereby supporting the safe, sustainable, and engaging development of the discipline.

2 Race description

The "Beach Sprint" coastal rowing race is rather different from classic rowing which takes place over a straight 2000 m distance within well-defined and demarked lanes, starting with the rowers already on the boats on their seats with oars in their hands. For example, as shown in Fig. 1, a solo Beach Sprint C1× race starts on land with the competitors running a short (10–50 m) sprint on the beach to reach the boat, held in position in the water typically by two or more boat handlers, depending on weather conditions. Regulations [5] require that when there are two or more boat handlers, there must be at least one male boat handler and one female. The rower then gets on the boat and rows outwards whilst maneuvering around three co-linear buoys arranged with the first buoy placed 85 m from shore, second buoy at another 85 m and last buoy a further 80 m out. On reaching the last buoy, the rower makes a return either in a straight line (slalom out / straight in, the version used in the 2022–2024 World Championships, see Fig. 1a-i) or a slalom (slalom out / slalom in format). Upon reaching shore, the rower jumps out of the boat and runs back to the finish/start position, pressing the "finish button". These races are typically one against one, with the winner determined by whoever presses the finish button first, after taking account for any time penalties. Apart from the solo races, the 2028 Los Angeles Olympic Beach Sprints will also feature mixed doubles (C2×), with one male and one female athlete, where only one rower runs in/out. Mixed doubles and mixed quads (C4×+, a coxed boat rowed by four athletes, two males and two females) are also raced at World Championships. Also, the initial stages of the Championships are typically run using the "processional time trial" format (see Fig. 1a-ii), where rowers compete one after the other, for the best time.

3 Risks and safety considerations

Whilst this may sound simple, in practice the races are adrenaline-rich and unpredictable, particularly if the weather and beach conditions are anything like the 2022, 2023 and 2024 World Championships or the 2023 Mediterranean Games in Crete, when several races could not be held as scheduled for athlete safety reasons. Probably, it is this added element of risk, adventure and degree of uncertainty – a bridge between classic rowing and the more extreme water sports – which gives beach sprint coastal rowing its true appeal.

As with any radical change, this revamp in the manner how the sport of rowing is conducted at the highest levels presents challenges along with unique opportunities for growth, innovation, and research and development, particularly in risk management and sports engineering.

Foreseeable risks for the on-water part of the race include tripping whilst embarking/disembarking the boat, swamping, capsizing, collisions, loss of boat control, equipment failure, etc., all of which may lead to traumatic injuries [6–8]. Although coastal boats are wider, shorter and more stable than their classic flat-water counterparts (see Table 1), capsizing is generally considered as a realistic hazard both during training and competition, especially when wind, swells, surf, or breaking waves are present. To mitigate these risks, safety precautions must be taken. Race organisers should select suitable venues and continuously monitor environmental conditions. Rowers and coxswains must also be well versed in safety protocols and know what to do if the boat swamps or capsizes (a requirement in the World Rowing Rule Book [5]) with capsize and re-entry drills being required parts of training [8]. The sections of the racecourse presenting the greatest risk in terms of boat stability and odds of capsizing are the mid-course 180° buoy turn and the landing/approach to the beach. The 180° turn is a high-risk phase because, during the manoeuvre, the boat temporarily assumes a beam-on orientation relative to the wind and wave direction. This lateral exposure generates heeling moments which, when combined with high speed or the impact of an incoming wave, may compromise the boat's transverse stability and increase the likelihood of capsizing. The beach landing phase is critical due to the progressive reduction

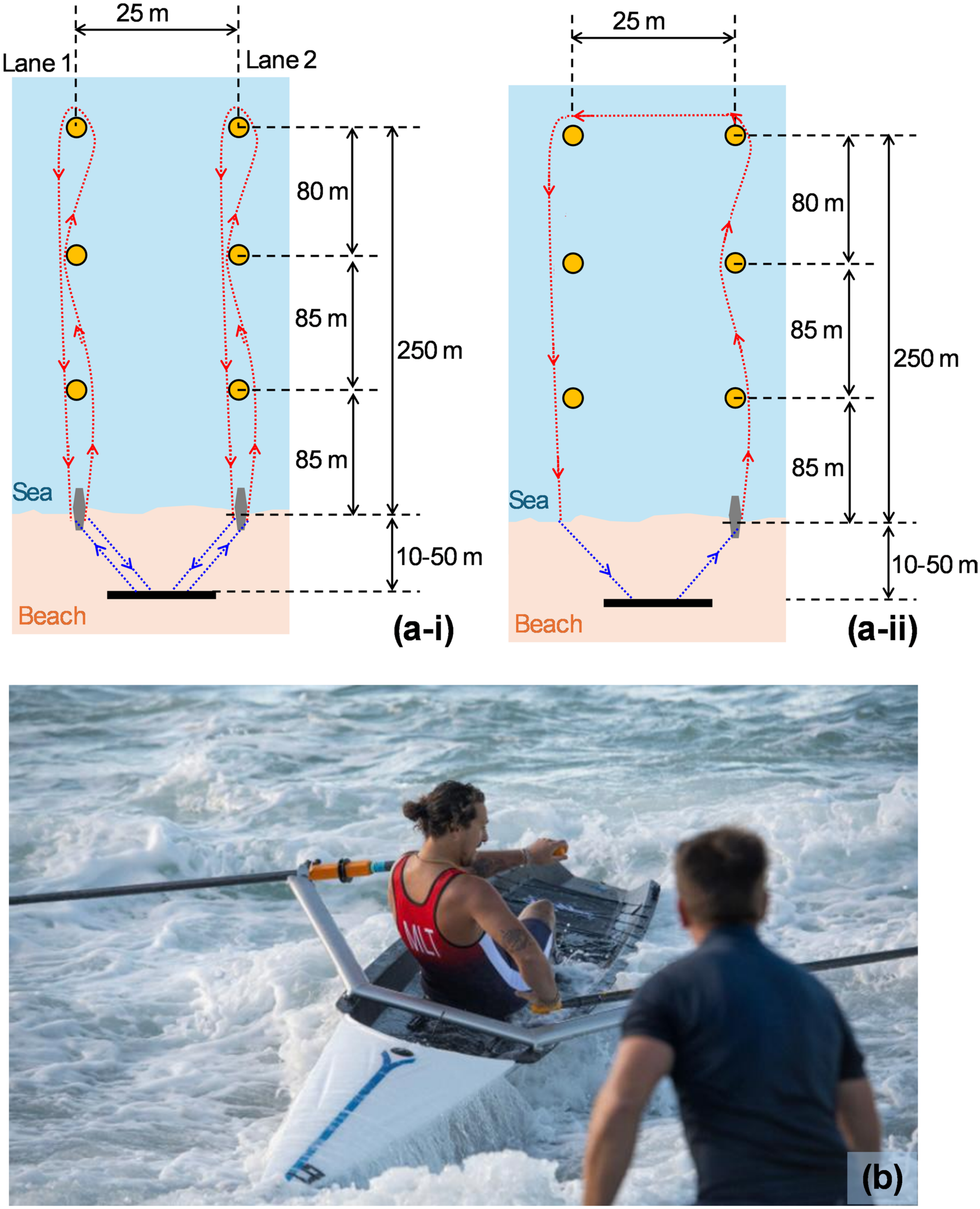

Fig. 1 **a** The race format of the Beach Sprint races in the (i) one against one, and (ii) processional time-trial format; **b** the C1× single rowing boat typically used in coastal rowing (taken from the 2024 World Championship, Image courtesy of Vittorio Puccio)

Table 1 A comparison of the coastal boat specifications (C1×, C2× and C4×+) with their most similar flat-water boat. Unless otherwise indicated, data taken from the World Rowing Rule Book[5]

Single		Flat water boat	Coastal boat
	Length (m)	7.2–8.4*	6.0 max.
(1× vs. C1×)	Width (cm)	26–29.5*	75.0 min.
	Minimum weight (kg)	14	35
Double	Length (m)	9.0–10.2*	7.50 max.
(2× vs. C2×)	Width (cm)	33.5–39.7*	100.0 min.
	Minimum weight (kg)	27	60
Quad	Length (m)	11.7–12.8*	10.70 max.
(4× vs. C4×+)	Width (cm)	40.3–48.0*	130.0 min.
	Minimum weight (kg)	52	130

* Data relating to typical racing shells manufactured by Filippi (https://www.filippiboats.com/). Note that World Rowing[5] does not dictate maximum lengths or minimum widths for the standard flat-water boats, with the only requirement being that they must all be longer than 7.2 m

Table 2 A sample of a "Weather Matrix'. Adapted from World Rowing's Coaching Coastal Rowing / Coastal Rowing Race Module by Guin Batten OLY (see Supplementary Information).

Outcome	Green	Amber	Red
	Proceed with caution	Proceed with additional safety measures / Postpone / Cancel	Postpone or cancel
Wind (Beaufort scale)	< Force 4/5	Force 4/5	Force 6+
Shape of wave / beach slope- *augmenting risk of boat "up-ending"*	Low	Occasional	Most waves
Breaking wave height	<0.5 m	0.5–1 m	>1 m
Temperature	Normal for competitors	Uncomfortable but can be mitigated with suitable clothing and shelter	Too hot or too cold
Visibility			Less than 250 m or dark
Lightning			30 s between lightning and thunder
Beach material	Sand	Sand & a small number of round pebbles	Sharp stones and large rocks
Pollution / Sea creatures	Low	Moderate	High

in water depth, which causes an increase in wave height and steepness (the shoaling phenomenon [9, 10]). As boats approach the shoreline, this phenomenon can cause them to enter into a surfing or planing phase on the wave. Whilst this, if used well, can reduce race times, it also increases the risk of capsizing during the subsequent descent from the wave crest due to an asymmetric loss of hydrodynamic support. This often leads to a pronounced lateral heel commensurate with wave height and boat speed. Excessive lateral heel is known to reduce stability and may lead to capsizing if the crew cannot counterbalance it with appropriate body movement, oar placement, or corrective strokes. Corrective measures (e.g. rowing at a slight angle to the waves) must also be taken when faced with side waves that produce yaw and roll that destabilise the boat and move it sideways.

Paramount to effective risk mitigation is the selection of an appropriate Beach Sprint venue. As noted in its coaching manuals (see Supplementary Information), World Rowing, the world governing body for the sports of rowing (formerly known as FISA), advises organisers to aim for a clean, sandy, rock-free and sheltered beach with an even gentle slope as this favours the formation of softer "spilling" waves rather than powerful "dumping" waves. Suitable wave conditions are spilling waves breaking 10–20 m from the shoreline, with wave height preferably under half a meter (maximum one meter). Tidal conditions must be carefully assessed, as low tide may expose rocks and other submerged hazards or extend the distance to the water, while high tides may eliminate usable beach space. Wind is also a key factor, so a sheltered beach is preferable to prevent wind-driven waves from disrupting racing. The prevalent wind direction should also be considered as it influences wave behaviour and associated risks. Strong offshore winds, blowing from land to sea, increase the risk of crews being blown seaward. Conversely, strong onshore winds, blowing from sea to land, amplify wave height and surf intensity, augmenting odds of capsizing, equipment damage and athlete injury.

To support race-day decision-making, World Rowing proposes the adoption of a 'weather matrix' (see example in Table 2) categorising conditions as "Green" (proceed with caution), "Amber" (proceed with additional safety measures, postpone, or cancel), or "Red" (postpone or cancel). This matrix factors in environmental variables such as visibility, electrical storms, marine hazards, pollution, and sea conditions likely to lead to boat capsize or damage (e.g. wind strength, wave height, and breaking behaviour). Races are not to be held when the wind is stronger than F6 on the Beaufort scale, waves are higher than 1 m, there is a jellyfish infestation or similar hazard, or visibility is so low that athletes cannot see the buoys.

4 Athlete protection and safety gear

The main and most immediate input by the sports engineering community is likely to be needed in the development of appropriate safety gear to be worn by athletes in the more extreme conditions (see Fig. 1b for a better appreciation of typical race conditions). In particular, the development of head gear to protect beach sprint coastal rowers from impact injuries and concussions is desirable. As noted in a recent study by De Leo et al. [7] beach sprints rowers may be more susceptible to concussion than classic rowers, given the transitions in and out of the rowing boats. Such gear must be carefully designed to strike the correct balance of being able to provide protection without hindering movement or visibility, even when wet. Here it must be emphasized that safety and protection gear, such as safety helmets or floatation jackets, have not been typically used by rowers in flat-water events. Thus, athletes may be reluctant to use them due to the perceived risks of hindrance, reduced mobility, irritation or overheating. This presents a challenge for the sports engineering community to be more innovative from both the design and materials perspective. The use of materials such as auxetic materials [11, 12], which are known for their suitability in such high-end sports applications [13–15], could be one of the avenues considered.

5 Boat and oar design

In terms of equipment, research is needed to develop or improve boats, oars and safety apparel (e.g. helmets) to ensure that this more extreme rowing discipline can indeed be practiced safely by all at reasonable costs, in rougher waters and under challenging weather conditions.

Regarding size and weight, coastal rowing boats are shorter, wider and heavier than standard rowing shells (see Table 1). World Rowing specifically states in its Rule Book [5] that boats used for coastal rowing beach sprints should have a minimum weight of 35 kg for the coastal solo (C1×), 60 kg for the coastal double sculls (C2×) and 130 kg for the coastal coxed quadruple sculls (C4×+). These are more than double the weights required by the Rule Book [5] for the most similar standard classic rowing ‘flat-water’ shells, i.e. 14 kg for single sculls (1×), 27 kg for double sculls (2×) and 52 kg for quadruple sculls (4×). Similarly, the rule book specifies a minimum width of 60 cm for C1×, 75 cm for C2× and 100 cm for C4×+, which are more than double the dimensions used by modern boat manufacturers for the construction of the more standard ‘flat-water’ shells (minimum width is not specified in the World Rowing Rule Book [5]). In terms of design, they are almost a hybrid between sailing boats, the traditional fixed-seat rowing boats [16], and the modern shells used in flat-water rowing. Consequently, they are slower but more stable and robust than standard rowing shells. Since the environment and race format for beach sprint coastal rowing are very different from the more standard “2000 m flat-water straight” race used for over a century in Olympic rowing, the boats need to be designed and manufactured differently to optimize both safety and performance during straight line rowing and buoy turns. In this respect research needs to look at hull design as well as materials, whilst staying within the regulations as set out by World Rowing [5]. The requirements are rather demanding. Boats should be robust enough to be capable of taking impacts and withstand a sea stirred by waves and wind, yet fast, light (see Table 1) and maneuverable enough to navigate smoothly, fast, efficiently and safely around buoys. Given that beach sprint coastal rowing is a relatively new discipline, systematic studies evaluating the safety characteristics of specific boat designs are currently lacking. In particular, research comparing how different hull designs perform in terms of safety versus speed, across a range of athlete anthropometric charatersitics, water and weather conditions remains limited.

In terms of materals, boats are typically constructed with fibre-reinforced composite outer skins and cellular (foam or honeycomb) or non-woven fabric core materials for lightweight, stiffness and strength. For example, the coastal double manufactured by Filippi Lido S.r.l. (model F85) uses carbon fibre-reinforced epoxy double skins with a honeycomb core with extra layers of high modulus carbon applied in strategic points of the boat structure, to reach higher stiffness [17]. The Elite+ range coastal rowing boats from Swift International Limited are manufactured using composite sandwich construction. The hull and saxboards incorporate a Coremat® (Lantor) core with a fibreglass outer skin, carbon cloth inner skin, and carbon reinforcement. The canvas decks use a Coremat® (Lantor) core with fibreglass skins, and the seat deck features a closed-cell polyvinyl chloride (PVC) foam core with fibreglass skins and additional fibreglass reinforcement.

[18]. Design must also permit easy entrance and exit of the athletes, both at the start and end of the race (which are integral components of the race itself) but also in the not uncommon unfortunate eventuality when a boat overturns. Furthermore, pointed objects (such as handles) should also not be present since impacts between athletes or boat handlers and boats are not uncommon.

Apart from boats, research should also be directed to the design of oars which are better suited for coastal rowing. Oar handles need to ensure a better grip, and stronger shafts or specially designed blades which are less prone to be adversely affected by waves during the recovery phase (i.e. when the blade is out of the water, between one pull and the next) may need to be developed. Further empirical research is also warranted into the performance of oar blade profiles under variable coastal rowing environments, including differing wave characteristics, current velocities, and wind-induced surface conditions. Establishing quantitative relationships between blade geometry and propulsion efficiency in different sea conditions could facilitate the development of predictive models and decision-support tools. Such models and tools would help athletes make an informed choice on blade selection relative to the specific sea conditions on competition day.

6 New materials for a new sport

The demanding requirements of this new sports discipline cannot be easily met with natural materials or classical boat designs. This provides the manufacturing and research community with an exciting challenge to develop new materials and manufacturing techniques that can be applied to new boat designs, tailor-made for coastal rowing beach sprints. In this respect, it would be interesting to assess whether auxetic and related materials with anomalous Poisson's ratio properties could offer an engineering solution. Whilst an extensive body of knowledge has been developed over the last decades [12, 19], commercially-viable manufacturing routes for real-world application of auxetic materials are a relatively recent development for the most part. These materials differ from their conventional counterparts in the manner that they behave under mechanical loading, with auxetics (negative Poisson's ratio materials, NPR) becoming wider rather than thinner when uniaxially stretched. Zero Poisson's ratio materials (ZPR) also behave rather anomalously by retaining a constant thickness when stretched or compressed. A negative or zero Poisson's ratio gives these materials useful properties for coastal boat design, including the unique ability to naturally adopt synclastic (dome-like) double curvatures (NPR) or cylindrical surfaces [20] (ZPR), both of which feature prominently in coastal rowing boats. More specifically, one could investigate the use of gradient auxetics [21–23] with tailor-made Poisson's ratio that changes gradually to morph (adapt shape) perfectly to the required curvature of the different parts of the hull. Uniform and gradient auxetic honeycombs and foams are well established and could meet the morphing/complex requirements for core materials used in coastal rowing boats. Moreover, it is well known that auxetics benefit from various other enhanced properties that should feature in a good coastal boat, including high indentation and impact resistance [24–27] and fracture toughness [28, 29]. Such property enhancements make auxetic composites, for example, suitable materials even for the aerospace industry [23, 30]. Recent studies demonstrate that well-designed auxetic sheets can enhance the structural resilience of glass-fibre reinforced plastic (GFRP) planing hulls against slamming impacts [31]. Moreover, carbon fibre-reinforced composites can themselves be designed to be auxetic [29], which would be important in terms of matching to an auxetic honeycomb or foam core Poisson's ratio, and also for improved impact response. This is particularly relevant for coastal rowing boats, which, during beach sprint training and racing, are frequently subjected to bow slamming when descending waves and to high-energy impacts during landings. Incorporating auxetics into coastal rowing boat hulls has the potential to extend their service life and reduce their maintenance costs (through improved fracture toughness and reduced damage volume under impact in auxetic composites [29], for example). This is an important consideration if coastal rowing is to grow at the grassroots and club level where finanicial resources are often scarce. Recently, auxetic metasurfaces (structured, two-dimensional lattices having in-plane NPR) have been proposed and shown to have unique strain-responsive superhydrophobic wetting potential [32], providing a potential route to improved hydrodynamic performance of boats. Auxetic composite, textile and cellular solid materials may also provide innovative solutions for better oar handles [33, 34] and apparel. These would draw on the recent introduction of auxetic material in the end of the grip of tennis rackets to increase shock absorption under impact [35], leading to enhanced 'feel' between the athlete and equipment [33–35].

The introduction of new materials must also recognise and address the critical issue of environmental sustainability. Consideration needs to include the carbon footprint of the full processing and transportation routes, re-use and end-of-life recycling. The latter is a key issue for composite materials and is driving the use of biodegradable natural and bio-based materials. The combination of low density, comparable strength and modulus, and high damping capacity, are leading to flax fibres replacing glass and carbon fibres in some applications, including in racing sailboats [36]. Hemp fibres also have potential in composites due to their high strength and stiffness [37], and in apparel due to their antibacterial properties [38], resilience and durability. High moisture absorption and breathability properties make bamboo fibres excellent candidates for apparel applications. From a sustainability perspective, the use of such bio-based eco-friendly (not harmful to the environment) materials is expected to offer long-term environmental benefits, including limiting the release of microplastics into the sea as boats are inevitably damaged with use. It would also be interesting to evaluate whether a new generation of eco-friendly auxetics [39, 40] made from natural fibres could be developed sufficiently to become suitable for use in coastal rowing boat manufacturing.

7 Medical and training aspects

In addition to the development opportunities for sports engineers, additional research is also needed from the medical and sport disciplines to transpose the vast amount of knowledge developed on classic rowing to Beach Sprints. New training programs, which are specific for Beach Sprint Coastal Rowers may need to be developed and their effectiveness scientifically evaluated. We are likely to see the emergence and retraining of rowers with a specialization in coastal beach sprint. For example, key and essential determinants in beach sprints are agility and reaction time, the training for which may not be sufficiently incorporated in the existing classic rowing training programs. It is also well-known that shorter athletes are often able to manoeuvre more easily. These desirable new components of physical fitness to be a top beach sprint rower may explain why the anthropometric characteristics of current top beach sprint rowers seem to be different than for the classic rowing requirements of being taller and heavier [41].

We also note that coastal rowing beach sprint race durations are considerably shorter than the classic 2000 m flat water races, typically lasting between 140 and 240 s, depending on boat type, sex and environmental conditions. From a physiological perspective, we may deduce that the metabolic energy required during coastal beach sprint competitions is supplied by both the anaerobic glycolytic and aerobic systems, as opposed to standard classic rowing, where the metabolic energy is supplied predominantly by the aerobic system. As discussed elsewhere, research suggests that for maximal efforts lasting 120–240 s, energy contributions would have a higher anaerobic component (estimated as ~ 37% anaerobic and ~ 63% aerobic at 120s, and ~ 21% anaerobic and ~ 79% aerobic at 240s) [42] compared to the classic rowing events where ~ 13% anaerobic and ~ 87% aerobic are not atypical [43]. Moreover, the unique dynamics of beach sprint racing – such as mounting and dismounting the boat, stopping to round a mark, and re-launching – introduce intermittent breaks that require athletes to generate repeated high-intensity accelerations. Consequently, the anaerobic contribution is likely to be even higher than what the standard models predict [42], making the physiological difference between beach sprints and classic rowing even more pronounced. Given all these differences, international rowing federations will most likely modify their talent identification and athlete development programs to win Olympic gold medals.

There are many publications discussing the health-promoting effects of classic rowing [44, 45], or the prevalence and risk of injuries from rowing [46], which remain tied to increases in training frequency, intensity and volume. It is, then, essential to study how well these apply to coastal rowing in view of the fact that coastal rowing beach sprint is an open water sport with the relative characteristics (wind, wave height, sea undertow, jump in and out of the boat, stopping and turning the boat and beach running, weight of the boat, etc.) being different from those in classic flat-water rowing. A recent study by DeLeo et al. [7]. suggests that, in addition to the injuries typically sustained by classic rowers, coastal rowers may be more susceptible to hamstring injuries (as a result of the running sprints on land) and concussion. As this rowing format is relatively new, it is not yet clear how these changes will affect injuries in elite athletes in the future, and whether the existing sports equipment (including boats and oars) need to be modified to minimize risks of injuries. In this context, wearable sensors, inertial measurement units, Global Navigation Satellite Systems (GNSS) and on-board or shore-based video analysis may provide valuable insights into boat kinematics, athlete load, movement coordination and environmental interactions in the dynamic open-water setting. The integration of such well-researched technologies [47, 48], could facilitate objective performance monitoring, individualized training prescription and injury risk assessment in coastal beach sprint rowing.

8 Future prospects

Moving forward, we recommend a multifaceted approach to research and monitoring. This spans from engineering design and manufacture of better and safer racing boats and apparel to evidence-based medical monitoring specifically tailored to elite rowers, under-19s (where, in consideration of the specific age factors in development, new training programs must be considered), masters and amateurs. Furthermore, technical aspects must be considered to refine competition rules so as to ensure athlete safety at all times. To achieve this, scientists and engineers must work together with coaches, athletes, umpires and medics with the common goal of developing this new sports discipline in a safe manner. Research is required to develop scalable fabrication processes and to rigorously evaluate the environmental impacts and long-term durability of new or emerging materials, particularly under the harsh conditions typical of coastal marine environments. This will establish the feasibility of such materials for sustainable and commercially-viable maritime applications.

Systematic and analytical studies are also needed to formally determine the optimal execution of specific race elements (e.g. landings or turning around buoys). This will require examining how rowing technique, oar and body placement, turning radius, etc. need to be tailored to different boat and athlete characteristics under a wide range of water and weather conditions.

This burgeoning sport discipline thus presents a unique opportunity for sports engineers to develop new products and improve existing ones, while honoring the rower-sea-nature relationship, which is increasingly narrow and inseparable. This is also most timely, in light of the recent developments with the inclusion of Rowing Beach Sprints in the 2028 Los Angeles Olympic Program. Seizing the opportunity is essential to support the growth and development of coastal rowing beach sprints, and the efforts being made by World Rowing to open up this discipline to para rowers, thus making it a truly inclusive sport.

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