DESIGN OF A MULTI-CHAMBER ROTATIONAL BOTTLE CAP FOR PHASE-BASED HYDRATION SUPPLEMENTATION

Weizhen WANG[1], **Zhou MU**[1]
[1]Dalian Polytechnic University, China

ABSTRACT
Hydration and nutritional supplementation play a crucial role in maintaining performance and physiological stability during endurance sports. However, existing hydration solutions—such as traditional water bottles, wearable hydration packs, and smart bottles—are generally limited to single-liquid supply and fail to adapt to phase-based hydration needs. To address this issue, this study proposes a multi-chamber rotational bottle cap that supports phase-based hydration through independent liquid storage and one-handed switching. The design follows a design-driven optimization approach informed by the principles of modular design, affordance, human-centred ergonomics, and temporal adaptability, achieving a balanced integration of functionality, usability, and mechanical stability. A questionnaire survey was conducted among 30 participants with endurance training experience, evaluating four dimensions: one-handed user operation, leakage prevention and flow stability, visual identification, and willingness for multi-chamber switching. Most feature comparisons showed no significant difference, indicating overall functional balance, while the difference between visual identification and switching willingness was significant ($t = -2.48$, $p = 0.019$), reflecting users' stronger preference for the switching function. These results confirm that the proposed design effectively meets user expectations for operational stability and functional reliability, providing a new direction for the human-centered and wearable design of sports hydration equipment.

Keywords: Multi-chamber rotational bottle cap, Endurance sports, Phase-based hydration, Functional product design, User operation

1 INTRODUCTION

During endurance sports, hydration and nutritional supplementation are essential for maintaining athletic performance and ensuring physiological stability. Inadequate intake can lead to fluid loss, electrolyte imbalance, and energy deficiency, which in turn may cause performance decline, fatigue, and even potential health risks [1]. Although the human body relies on subjective cues such as thirst to initiate drinking behavior, research has shown that these signals typically appear only after dehydration has occurred, making them unreliable indicators for effective hydration management during prolonged and high-intensity exercise [2,3]. Previous studies have revealed that participants in marathon and trail-running events often experience insufficient hydration and energy intake, with nearly one-third failing to meet recommended levels [4]. Furthermore, existing hydration devices generally feature single-chamber structures, which limit functionality and compromise both operational convenience and user comfort [5]. These limitations underscore the need for innovative hydration solutions that better address the complex demands of endurance sports. In response to these challenges, this study introduces a novel bottle cap design and applies a design-driven optimization approach combining modularity, affordance, human-centred ergonomics, and temporal design. These considerations enable a balanced integration of mechanical stability, intuitive interaction, and user comfort.

Subsequently, this study conducted two research activities to examine the proposed multi-chamber rotational bottle cap design from the perspectives of domain analysis and user evaluation (see Figure 1). First, a review of current academic studies, commercial innovations, and hydration practices in endurance sports was carried out to identify major limitations in functionality, ergonomic performance, and adaptability, providing a theoretical foundation for design improvement. Second, a questionnaire survey was conducted among users with endurance training experience to evaluate the design's performance and acceptance across four dimensions: one-handed user operation, sealing and flow stability, visual identification, and willingness for multi-chamber switching. Quantitative results indicated that users generally perceived the design as both practical and innovative, with the multi-chamber switching feature receiving the highest evaluation. The study systematically reviewed existing research and market developments, proposed the design concept, and validated its performance through user assessment.

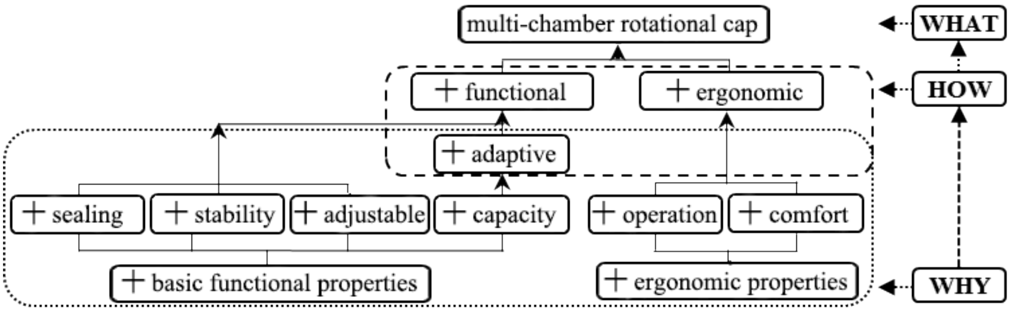

Figure 1. Research logic relationship of the multi-chamber rotational bottle cap design

2 RELATED WORK

2.1 Current Academic Research in Bottle Cap Design

Current scholarly investigations into bottle cap design have predominantly concentrated on material innovation, ergonomic performance, and user adaptability. Alternative materials such as 100% wood pulp fiber thermoforming have been proposed as plastic substitutes, offering sustainability but with limited durability under prolonged liquid contact [6]. Structural and ergonomic studies demonstrate that cap geometry significantly affects opening torque and user effort, with PET variations influencing comfort and perceived difficulty [7]. For vulnerable groups, vacuum-release aluminum lug closures have been developed to reduce opening force while maintaining sealing integrity [8]. Tests with elderly participants confirmed correlations between torque, hand size, and grip load, offering guidance for easy-open design [9,10]. Research on children further identified only three grip strategies for child-resistant closures, underscoring the balance required between safety and usability [11].

The European Union's mandatory regulation on tethered caps has likewise stimulated both academic and industrial inquiry into usability and consumer acceptance. While users acknowledge the environmental benefits of tethered designs, survey data indicate that safety and user operation are regarded as higher priorities [12] (see Table 1).

Table 1. Current Academic Research in Bottle Cap Design (2020–2024)

Research Dimension	Representative Study	Findings and Limitations
Material Innovation	Chinga-Carrasco et al. (2024)	100% wood pulp fiber thermoforming; low durability under long-term liquid exposure.
Structural Design and Ergonomics	Silva et al. (2015); Qiu et al. (2024)	Cap geometry influences torque and comfort; vacuum-release lug closure reduces force but challenges sealing.
Adaptation for Vulnerable Groups	Hamza & Kineber (2023); Yamashita & Yokoyama (2019)	Torque related to hand size and load; lab-based studies guide easy-open design.
Child Safety and Usage Strategies	Wilson & Bix (2021)	Limited child grip strategies; balance between safety and usability.
Regulations and Usability	Sidel (2021); Lang & Bastians (2024)	EU tethered-cap policy drives design; safety and convenience prioritized over sustainability.

2.2 Commercial Innovations in Bottle Cap Design

Recent commercial innovations in bottle cap design emphasize sealing and on-demand dispensing. Vessl, Pont, and Smart Cap Dosage exemplify this trend, with various mechanisms for integrating concentrated liquids at the point of use (see Table 2). BlastMax enables precise single-dose dispensing with visual traceability [13], while B-CAP Europe's Eco Refill system employs a reusable rotary cap to reduce packaging waste through controlled release during rotation [14]. Heinz has introduced a dual-liquid dispensing cap for condiments, allowing simultaneous release and enhancing user flexibility [15]. Although these solutions have gained traction in beverages, supplements, and condiments, their application in personalized hydration during physical activity remains limited, indicating potential for future innovation.

Table 2. Commercial Innovations in Bottle Cap Design (2012–2024)

Company / Brand	Cap Innovation Type	Key Features and Applications
Vessl	Pressure-driven cap system	Pressure-activated mixing; reduces single-use packaging; applied in beverage and health products.
Pont – TWINCAP	Dual-chamber cap	Sealed inner chamber; mixes contents upon rotation; used in nutraceutical packaging.
BlastMax	Dosage-controlled cap	Precise single-dose release; visualized dispensing enhances user interaction.
Smart Cap Dosage (Amcor)	Integrated metered-dose cap	Combines capping and dosing; suitable for pharmaceuticals and concentrated drinks.
B-CAP Europe – Eco Refill	Reusable dispensing cap	Enables concentrate mixing during rotation; improves efficiency and reduces waste.
Heinz (The PackHub)	Dual-flow dispensing cap	Dispenses two sauces simultaneously; offers flexible flavor experience.

3 CONCEPT DESIGN

3.1 Design Principle

The multi-chamber rotational bottle cap is developed based on Stellingwerff's nutritional periodization theory [16], which emphasizes dynamically adjusting nutrient intake across training phases to optimize endurance performance and recovery. Translating this concept into a functional product design, the cap achieves phase-based hydration through modular chambers and a rotational control mechanism. Studies show that human requirements for water, electrolytes, and carbohydrates vary with exercise duration and intensity [17,18,19], aligning with Temporal Design, which advocates adaptability to time-evolving processes [20]. The design addresses the needs of multi-component supplementation and phase-based hydration in endurance sports, aiming for quick one-handed operation, independent sealed storage, and improved chamber recognition. By integrating a multi-chamber structure with a rotational switching mechanism, users can flexibly control different supplement liquids, offering a more adaptive and efficient hydration strategy for endurance performance.

3.2 Key Structure and Functions

The proposed multi-chamber rotational bottle cap consists of three main components: a top knob, a central multi-chamber storage module, and a base platform. As shown in Figure 2a, the top knob serves as the core part of user operation. It is designed as an integrated component that incorporates three functional structures—an internal threaded column (1), a knob insertion interface (2), and an alignment scale (3) located on the outer rim. The threaded column (1) connects with the spiral groove (4) on the upper surface of the storage module, ensuring smooth rotation and reliable sealing through a stable threaded engagement. During operation, the alignment scale (3) on the knob corresponds to the indicator line (12) on the base platform, guiding the user to accurately select the target chamber.

As illustrated in Figure 2b, the multi-chamber storage module adopts a cylindrical configuration and is circumferentially divided into three fully independent chambers (5, 6, 7). Each chamber is equipped with a sealing cover, the position of which is indicated by dashed lines in the figure. This design allows for the independent storage of various types of liquid supplements, such as electrolyte solutions, carbohydrate beverages, or recovery fluids. A bottom outlet (8) is provided for each chamber. When the knob is rotated, the interaction between the threaded column (1) and the spiral groove (4) synchronously drives the rotation of the storage module, aligning the outlet of the selected chamber precisely with the flow channel of the base platform.

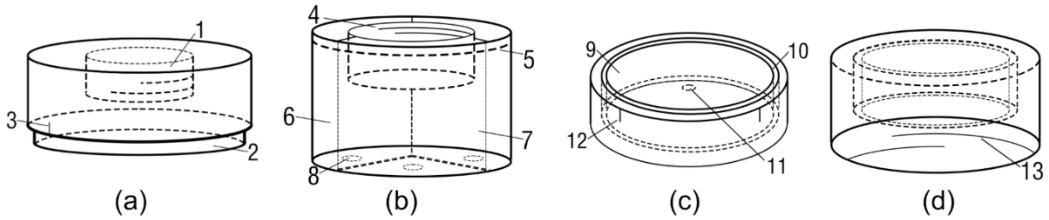

Figure 2. Structural composition of the multi-chamber rotational bottle cap: (a) top knob. (b) multi-chamber storage module. (c) base platform. (d) base platform (bottom).

The base platform connects the knob with the multi-chamber storage module and attaches to a beverage bottle via an internal spiral thread (Figures 2c–d). It includes a connection groove (9), a bottom insertion slot (10), and a central outlet (11). When the user rotates the knob to align the alignment scale (3) with the indicator line (12), the bottom outlet (8) of the selected chamber connects with the central outlet (11), forming a continuous flow path that allows the supplement liquid to flow into and mix with the bottle's contents. When the knob is rotated away, the channels misalign, closing the flow path to prevent leakage or cross-contamination. The inner wall contains a spiral thread (13), enabling the cap to be securely screwed onto the bottleneck for reliable sealing and easy disassembly, refilling, and cleaning. Other chambers operate under the same principle.

4. DESIGN METHODS AND EVALUATION

4.1 Structural Design and Modeling

The preliminary sketches and structural concepts in Section 3.2 were used to create 3D models of the multi-chamber rotational bottle cap in Blender, with each component color-coded for clarity. According to the modular product architecture theory proposed by Dahmus, complex products should consist of independent yet interlocking modules that are connected through standardized interfaces to enhance adaptability and facilitate maintenance [21]. Following this principle, each module in this design performs an independent function and can be assembled through coordinated operation among the modules to achieve overall structural stability. The knob, designed as an integrated structure, is shown in a bottom view (see Figure 3a). It features a streamlined blue metallic finish for visual appeal and tactile comfort. With a diameter of 4 cm and height of 2 cm, it ensures comfortable one-handed use. Structurally, it includes an internal threaded column (green part), 1.5 cm in diameter and 0.8 cm long, that engages precisely with the spiral groove of the central multi-chamber storage module for smooth, low-friction rotation. For stability, the knob insertion interface (purple part)—3.6 cm in diameter, 0.5 cm deep, and 0.1 cm thick—connects securely with the base slot. The alignment scale (yellow part), 0.4 cm wide, guides accurate liquid output. High-contrast markings improve visibility, while the overall design balances functionality and aesthetics for an intuitive user experience.

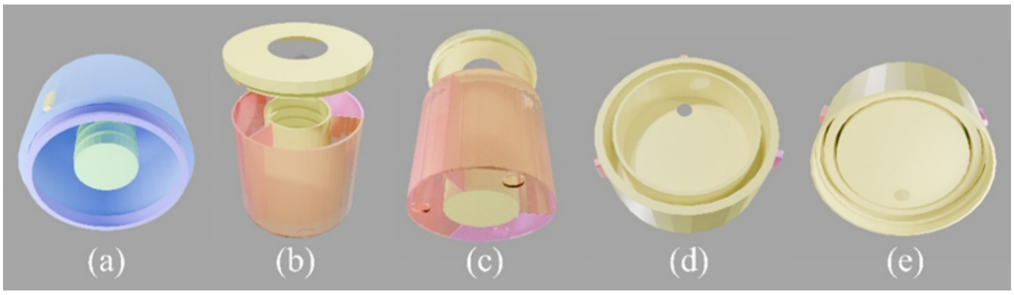

Figure 3. Components of the multi-chamber rotational bottle cap:(a) top knob. (b) central multi-chamber storage module. (c) central multi-chamber storage module (bottom view). (d) base platform. (e) base platform (bottom view).

The central multi-chamber storage module serves as a container for different supplement liquids, enabling independent storage and controlled output. The module is divided circumferentially into three chambers, each 3 cm in diameter and 2.6 cm in height, for storing various solution types (see Figure 3b). The outer shell, made of semi-transparent food-grade material, features color markings for quick identification—chamber A, B and C (orange, red, and pink parts). The design draws on the affordance and product-semantics theory by You and Chen, which emphasizes how users perceive possible interactions through visual and tactile cues [22]. At the center, a spiral groove (yellow part) with a 1.5 cm diameter and 1 cm height includes internal threads that match the knob's internal threaded column, ensuring a secure, low-friction connection. Each chamber has a 0.4 cm-high sealing cover (yellow part) for tight closure and ease of use, and a 0.4 cm bottom outlet (see Figure 3c) for smooth liquid discharge. This design allows efficient solution management and enhances visual appeal through vivid color contrast.

The base platform integrates structural support, connection, and liquid guidance functions (see Figure 3d). To ensure stability and ease of operation, it was designed as a cylindrical structure with a diameter of 4 cm and a height of 1.5 cm. The connection groove, 1.1 cm high, forms a smooth recessed cavity to secure the central multi-chamber storage module. Inside, a 0.4 cm diameter, 1.1 cm height bottom insertion slot precisely fits the knob insertion interface, forming a stable, integrated structure. The central outlet (0.6 cm diameter) aligns with the bottom outlet, creating a continuous channel for smooth, sealed discharge. Three indicator lines matching the colors of the chambers, corresponding to the knob's alignment scale for accurate operation. The edge features a smooth arc transition for ergonomic comfort and seamless integration with the bottle body. The inner wall contains a spiral thread (see Figure 3e) for secure screwing to the bottleneck, ensuring overall stability and airtight sealing.

4.2 Design Operation and Theoretical Evaluation

The proposed design was evaluated across three dimensions: operation, ergonomics, and application to verify its suitability for endurance sports. The multi-chamber rotational bottle cap features a detachable design combining spiral and insertion mechanisms (see Figure 4a). During assembly, the sealing cover is opened to fill chambers A, B, and C with different supplements. To prevent leakage, the sealing cover must be closed firmly before assembly (see Figure 4b). The top knob connects to the central multi-chamber storage module through engagement between its internal threaded column and spiral groove on the module's upper surface, ensuring precise alignment and stable tightening (see Figure 4c). Once engaged, the top knob's insertion interface aligns with the bottom insertion slot to complete assembly and enable fluid transfer (see Figure 4d). Operationally, this operational mechanism validates the multi-layer affordance model proposed by Pols, which interprets user–system interaction across the levels of manipulation, effect, and activity [23]. The design emphasizes single-handed usability—users can switch between supplements by rotating the knob, while the alignment scale and high-contrast markings provide clear feedback even in motion or low light. The detachable structure simplifies refilling and cleaning, enhancing convenience.

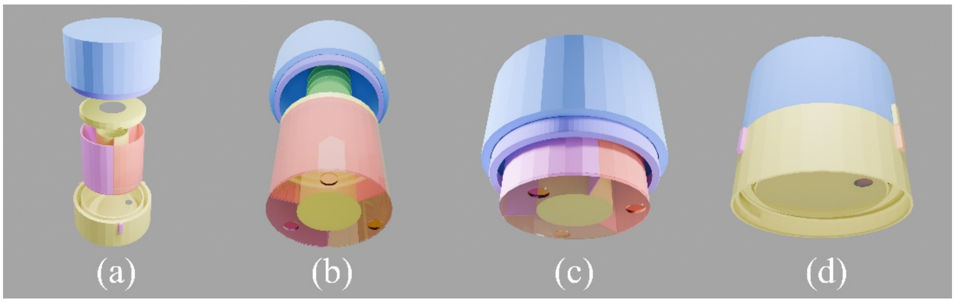

Figure 4. Assembly process of the multi-chamber rotational bottle cap: (a) exploded view of the cap components. (b) sealing the storage module; (c) connecting the knob and the storage module. (d) aligning the insertion interface with the base slot.

The human-centred design framework emphasizes intuitive interaction achieved through physical, perceptual, and cognitive compatibility [24], which guided the ergonomic optimization of the proposed design to ensure smooth operation and user comfort. Rotating the top knob drives the central multi-chamber liquid storage module synchronously. When the alignment mark on the knob matches the indicator line on the base, the outlet of the selected chamber connects with the bottom outlet, forming a continuous flow channel that lets liquid flow directly into the bottle. In the non-operating state, the outlets are misaligned, ensuring a tight seal and preventing leakage. The design is optimized for mechanical rationality and grip stability, with torque adjusted for smooth switching under minimal effort, reducing fatigue and errors. Within this concept, the multi-chamber rotational bottle cap demonstrates superior adaptability and usability, providing an ergonomic and structural foundation for phase-based hydration in endurance sports and supporting subsequent modeling and validation.

At the application level, the multi-chamber structure supports a phase-based hydration strategy that meets nutritional needs across different stages of training and competition. This design allows users to flexibly select supplement types by exercise phase, maintaining energy and fluid balance without disrupting rhythm. Moreover, this design reflects the socially responsible design perspective proposed, which integrates product interaction with user motivation and behavioral feedback to promote positive user experiences and responsible usage behaviors [25]. Empirical evidence suggests that water alone during exercise often fails to sustain fluid homeostasis, while electrolyte beverages taken before or after help maintain electrolyte balance, plasma volume, and reduce fatigue [26]. These findings provide theoretical support for phase-based hydration in enhancing performance and recovery.

4.3 User Evaluation of the Multi-chamber rotational bottle cap

A questionnaire survey was conducted among individuals with endurance sports experience to assess the design rationality and user acceptance of the multi-chamber rotational bottle cap. A total of 40 questionnaires were collected, and after excluding non-endurance participants, 30 valid responses were retained. Participants mainly engaged in running, cycling, and trail hiking. Using a five-point Likert scale, four dimensions were evaluated: one-handed operability, leak-proof performance, visual identification, and willingness to adopt the multi-chamber switching mechanism.

Table 4. Results of the Paired-Sample t-test for Design Feature Evaluation (n = 30)

Design Feature Comparison	t-value	p-value	Significance
One-handed operability vs Sealing	-0.528	0.602	Not significant
One-handed operability vs Visual identification	1.490	0.147	Not significant
One-handed operability vs Multi-chamber switching willingness	-0.902	0.375	Not significant
Sealing vs Visual identification	1.980	0.057	Marginal (approaching significance)
Sealing vs Multi-chamber switching willingness	-0.273	0.787	Not significant
Visual identification vs Multi-chamber switching willingness	-2.483	0.019	Significant ($p < 0.05$)

As shown in Table 4, paired-sample t-tests were conducted to examine differences among the four design dimensions. Most feature comparisons did not show statistically significant differences, indicating a generally balanced evaluation of both usability and functionality. The comparison between sealing and visual identification approached significance ($t = 1.98$, $p = 0.057$), suggesting that participants tended to value sealing performance slightly more than visual identification. The difference between visual identification and willingness to adopt the multi-chamber switching mechanism was significant ($t = -2.48$, $p = 0.019$), indicating that users expressed higher satisfaction with the functional switching feature than with visual identification. Open-ended responses further highlighted "leak prevention," "ease of cleaning," and "smooth switching" as key positive aspects of the design. Overall, the results suggest that the multi-chamber rational bottle cap effectively meets user expectations for operational stability and functional reliability in endurance sports.

5. DISCUSSION

5.1 Results and Design Implications

The questionnaire results show that the multi-chamber rotational bottle cap received consistently positive evaluations for functionality and operability. The significant difference between visual identification and switching willingness ($t = -2.48$, $p < 0.05$) indicates that users value functional adaptability and fluid control over static visual cues, reinforcing the design rationale grounded in Stellingwerff's nutritional periodization principle, which emphasizes that endurance athletes' nutritional needs vary dynamically and should be supported through phase-based structural mechanisms. Users' preference for switching reflects awareness of the temporal hydration strategy, demonstrating that the design successfully transforms theoretical concepts into an intuitive, time-responsive interaction aligned with Temporal Design theory, thereby achieving both physical component switching and temporal synchronization among user behavior, product interaction, and hydration rhythm.

From an ergonomic perspective, high user satisfaction with one-handed operability and leak-proof performance demonstrates effective biomechanical coordination among knob size, torque resistance, and sealing design—validating the ergonomic principles of the design. The comparatively lower score for visual recognizability suggests that users prioritize functional stability and performance reliability over aesthetic appeal, which aligns with the utilitarian demands typical of endurance sports contexts. Overall, these findings confirm the theoretical robustness of the design, establishing a coherent theory–design–validation loop and offering practical insights for the future development of wearable hydration systems.

5.2 Limitations and Future Work

This study relied primarily on user-reported perceptual data, and the sample size was limited. While the findings offer valuable insights into design trends, broader testing with larger and more diverse participant groups across multiple endurance scenarios is required. Future research should focus on prototype fabrication and ergonomic testing to evaluate the stability and comfort of the rotational mechanism, along with developing a compatible bottle body and wearable hydration systems. Incorporating system-dynamic thinking [27], which emphasizes temporal framing and multi-scale interaction, could position the design within a broader temporal and systemic context. Through iterative optimization and ergonomic validation, this study provides a pathway for advancing human-centered sports equipment design.

6. CONCLUSION

This study proposed a multi-chamber rotational bottle cap design to address the phase-based hydration needs in endurance sports. Through a systematic analysis of existing hydration products and related research, it was found that conventional sports bottles often feature single functionality and limited usability, making them inadequate for multi-component and stage-specific supplementation during prolonged exercise. To overcome these limitations, the proposed design adopts a multi-chamber structure that enables independent liquid storage and rapid switching, while the top knob allows for one-handed user operation. This configuration significantly enhances both the sealing reliability and operational convenience of the bottle cap. Informed by a design-driven optimization approach, the study integrates principles of modular design, affordance, human-centred ergonomics and temporal adaptability to refine the cap's structural performance and user interaction. The questionnaire results demonstrated strong user acceptance, with the multi-chamber switching feature receiving the highest satisfaction ($p < 0.05$), validating the effectiveness of the design in supporting phase-based hydration. Future work will focus on the fabrication of a physical prototype and real-world usability testing to further verify the structural stability and reliability of the design. Overall, this research not only provides a new human-centred and function-oriented design perspective for the development of next-generation sports hydration equipment but also demonstrates how design theory can serve as an optimization framework linking ergonomics, structure, and user experience across time-evolving scenarios.

ACKNOWLEDGMENTS

This work was partially supported by the Liaoning Provincial Social Science Planning Fund, and the Research Project on Economic and Social Development of Liaoning Province (2025lslybwzzkt-175); Liaoning Provincial Education Science Planning Project (JG25DB046).

REFERENCES

[1] Sebastiá-Rico J., Soriano J. M., Sanchis-Chordà J. et al. Analysis of fluid balance and urine values in elite soccer players: Impact of different environments, playing positions, sexes, and competitive levels. *Nutrients*, 2024, 16(6), 903.

[2] Kenefick R. W. Drinking strategies: Planned drinking versus drinking to thirst. *Sports Medicine*, 2018, 48(Suppl 1), 31–37.

[3] Armstrong L. E. Rehydration during endurance exercise: Challenges, research, options, methods.

Nutrients, 2021, 13(3), 887.
[4] de Moura R. C., de Moura Costa C., Ferreira C. P. et al. Hydration assessment and physical performance of mountain bike cyclists in competition in a hot environment. *Scientific Reports*, 2025, 15, 21183.
[5] Scheer V., Vieluf S., Bitter N., Christ L., and Heitkamp H.-C. The optimal weight carriage system for runners: Comparison between handheld water bottles, waist belts, and backpacks. *Frontiers in Physiology*, 2020, 11, 571221.
[6] Chinga-Carrasco G., Ruwoldt J., Pasquier E. et al. Development of a beverage carton closure cap based on 100% wood pulp fibres. *Journal of Cleaner Production*, 2024, 445, 141339.
[7] Silva D. C., Bonfim G. H. C., Paschoarelli L. C., Fabio D. R., Alves A. L., Merino E. A. D., Merino G. S. A. D., and Garcia L. J. Evaluation of two PET bottles caps: An exploratory study. *Procedia Manufacturing*, 2015, 3, 6245–6252.
[8] Qiu S., Saikia N., and Padilla-Zakour O. I. New aluminum lug closure reduces removal torque while ensuring hermetic seals in glass jars. *Food Protection Trends*, 2024, 44(4), 273–282.
[9] Hamza M. F. and Kineber A. F. Normative data on the maximum twisting force for an elderly person's sustainable life. *Sustainability*, 2023, 15(5), 4485.
[10] Yamashita S. and Yokoyama K. Study on opening motion of PET bottle cap for elderly people. *Journal of the Japan Society of Mechanical Engineers: Ergonomics*, 2019, 53, 734–740.
[11] Wilson C. J. and Bix L. Gripping strategies employed by young children aged 3–5 years when interacting with child-resistant push and turn closures used by pharmacies in the United States. *Applied Ergonomics*, 2021, 92, 103349.
[12] Sidel. Survey on tethered caps: Consumers prioritise product safety and user-friendliness. Available: https://www.sidel.com/en/packaging/tethered-cap-sv1-56 [Accessed on 2024, 30 September], (2021) 15 March.
[13] BlastMax. Measured dosing cap technologies. Available: https://www.blastmax.com [Accessed on 2025, 24 September], (n.d.).
[14] B-CAP Europe. Eco Refill B-CAP system. Available: https://b-cap.eu [Accessed on 2024, 24 September], (n.d.).
[15] The PackHub. Infusion system mixes liquids on the go. Available: https://thepackhub.com/innovation/infusion-system-mixes-liquids-go/ [Accessed on 2024, 24 September], (2024) 20 March.
[16] Stellingwerff T. A framework for periodized nutrition for athletics. *International Journal of Sport Nutrition and Exercise Metabolism*, 2019, 29(2), 141–151.
[17] Pérez-Castillo Í. M., Williams J. A. et al. Compositional aspects of beverages designed to promote hydration before, during, and after exercise: Concepts revisited. *Nutrients*, 2024, 16(1), 17.
[18] Li H., Early K. S., Zhang G. et al. Personalized hydration strategy to improve fluid balance and intermittent exercise performance in the heat. *Nutrients*, 2024, 16(9), 1341.
[19] Cao W., He Y., Fu R. et al. A review of carbohydrate supplementation approaches and strategies for optimizing performance in elite long-distance endurance. *Nutrients*, 2025, 17(5), 918.
[20] Pschetz L. and Bastian M. Temporal Design: Rethinking time in design. *Design Studies*, 2017, 56, 169–184.
[21] Dahmus J. B., Gonzalez-Zugasti J. P., and Otto K. N. Modular product architecture. *Design Studies*, 22(5), 409–424.
[22] You H.-C. and Chen K. Applications of affordance and semantics in product design. *Design Studies*, 28(1), 23–38.
[23] Pols A. J. K. Characterising affordances: The descriptions-of-affordances model. *Design Studies*, 33(2), 113–125.
[24] Giacomin J. What is human centred design? *The Design Journal*, 2014, 17(4), 606–623.
[25] Tromp N., Hekkert P., and Verbeek P. P. Design for socially responsible behavior: A classification of influence based on intended user experience. *Design Issues*, 2011, 27(3), 3–19.
[26] Choi D.-H., Cho J.-Y., Koo J.-H. et al. Effects of electrolyte supplements on body water homeostasis and exercise performance during exhaustive exercise. *Applied Sciences*, 2021, 11(19), 9093.
[27] Goss H. M., Tromp N., and Schifferstein H. N. J. Framing system dynamics for designers innovating in transitions. *International Journal of Design*, 2025, 19(1), 77–94.