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Out of the Mud: A User-Centered AHP-Based Approach

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ABSTRACT

This study used the Analytic Hierarchy Process (AHP) to prioritize ergonomic requirements for a wearable support system designed for intertidal zone fishermen. To address high physical demands and harsh environmental conditions, evaluation criteria were categorized into three dimensions: psychological, physiological, and operational. Eighteen experts (fishermen, designers, and fisheries specialists) conducted pairwise comparisons. Results indicated that lumbar protection was the highest-weighted requirement, followed by labor assistance and lightweight construction. Prototypes developed based on these priorities underwent field testing, demonstrating that the system enhances work efficiency and reduces fatigue by approximately 20%, confirming the effectiveness of integrating ergonomic considerations into product design. This study validates the value of AHP as a structured decision-making tool in ergonomics and provides a reference framework for small-scale industrial design in resource-constrained environments.

Keywords: AHP, Ergonomics, Wearable support, Fishermen, Human-centered design

INTRODUCTION

Manual labor is commonly associated with ergonomic risks, where workers are frequently exposed to repetitive motions, awkward postures, and high-intensity environments. These factors elevate the risk of musculoskeletal disorders, reduce work efficiency, and threaten occupational health sustainability (Smith et al., 2020; Li & Zhang, 2021). In industries such as construction, manufacturing, and healthcare, numerous studies have implemented ergonomic interventions and wearable assistive systems to mitigate these risks. For example, exoskeletons and back-support devices have been proven effective in reducing musculoskeletal injuries, enhancing comfort, and improving productivity (Jones et al., 2019; Kim et al., 2022).

However, despite substantial progress in these domains, research targeting marine and outdoor working environments remains limited (Wang et al., 2021). Intertidal fishermen, for instance, operate in muddy and unstable terrains while being continuously exposed to high humidity and saline conditions. Such environments exacerbate physical strain, while repetitive tasks such as bending, squatting, and load-bearing walking impose sustained stress on the lumbar spine and upper limbs, thereby increasing risks of chronic musculoskeletal injuries and intervertebral disc herniation (Chen et al., 2018; FAO, 2020). Thus, ergonomic interventions are urgently needed. Unfortunately, existing protective equipment and assistive devices often fail to simultaneously address comfort, adaptability, and durability. To address this gap, structured approaches are required to systematically capture and quantify fishermen's complex needs.

This study introduces the Analytic Hierarchy Process (AHP) (Saaty, 1980) as a methodological tool to identify and prioritize ergonomic requirements. By employing pairwise comparisons and priority ranking, AHP enables the systematic integration of multiple stakeholder perspectives, thereby guiding the design of an intertidal fishermen's wearable lumbar support system. Based on the AHP-derived priority results, a functional prototype was subsequently developed and refined through iterative testing. The physical prototype allowed for the validation of key ergonomic parameters, including functional configurations and anthropometric dimensions, ensuring that the final design aligns with both user needs and operational constraints.

RELATED WORK

Ergonomic research in recent years has increasingly emphasized the integration of wearable technologies and human-centered evaluation methods to address physical challenges in labor-intensive environments. Among various approaches—such as biomechanical analysis, motion capture assessment, pressure mapping, and electromyography (EMG) monitoring—wearable assistive systems have demonstrated great potential in reducing physical strain and improving work efficiency, while the AHP provides a structured means to evaluate and prioritize ergonomic needs based on user and expert input. This section reviews existing studies in these two domains to establish the theoretical foundation for the design and evaluation of the intertidal fishers' wearable lumbar support system.

Wearable Support Systems for Labor-Intensive Work

Wearable assistive devices are widely studied to improve workers' comfort, stability, and endurance in demanding tasks. Early studies on industrial and agricultural exoskeletons revealed that such systems can effectively reduce lumbar load and muscle fatigue, thus preventing long-term musculoskeletal disorders (Kazerooni, 2010; Toxiri et al., 2017).

Recent developments have moved toward lightweight, flexible, and modular wearable systems tailored for dynamic outdoor environments. For instance, Kim et al. (2021) proposed a soft exosuit integrating elastic fabrics and pneumatic actuators, which maintained natural movement while providing targeted lumbar assistance. Similarly, Lee et al. (2020) emphasized that ergonomic support in unstable, wet environments—such as intertidal zones—requires adaptive materials and structures to accommodate posture variability and resist water-induced degradation.

However, challenges remain in achieving fine-grained cleanability, sufficient lightweight balance, and durability in humid conditions. Addressing these gaps is essential for extending wearable ergonomic systems into marine or muddy workplaces, where long-term exposure and repetitive bending motions significantly increase fatigue risk.

Application of AHP in Ergonomic Design Research

The AHP has become a fundamental decision-support tool in ergonomic and product design research. By decomposing complex ergonomic problems into hierarchical structures—covering physiological, psychological, and operational dimensions—AHP enables systematic weighting and comparison of human factors (Vaidya & Kumar, 2006).

In practical applications, AHP has been used to evaluate design criteria such as comfort, usability, safety, and task efficiency (Liu et al., 2019; Wu et al., 2022). It facilitates the integration of quantitative analysis and expert judgment, supporting evidence-based optimization in wearable product design. For example, García (2010) and Zhang et al. (2021) demonstrated that AHP can effectively guide prioritization of ergonomic requirements in exoskeleton and support system development, ensuring user-centered functionality and adaptability.

In this study, AHP serves as the methodological core for assessing and ranking ergonomic needs among intertidal fishers, directly informing the structural configuration and usability refinement of the proposed wearable lumbar support system.

METHODOLOGY

From May to July 2024, field studies were carried out in two coastal fishing villages in Jiangsu Province, China. A total of 12 fishermen (8 males and 4 females, M = 41.2 years, SD = 7.9; range = 28–55 years) participated in semi-structured interviews addressing workload perception, tool interaction, and ergonomic constraints. Participants averaged 18 years of fishing experience, representing typical mid-career intertidal practitioners (Figure 1).

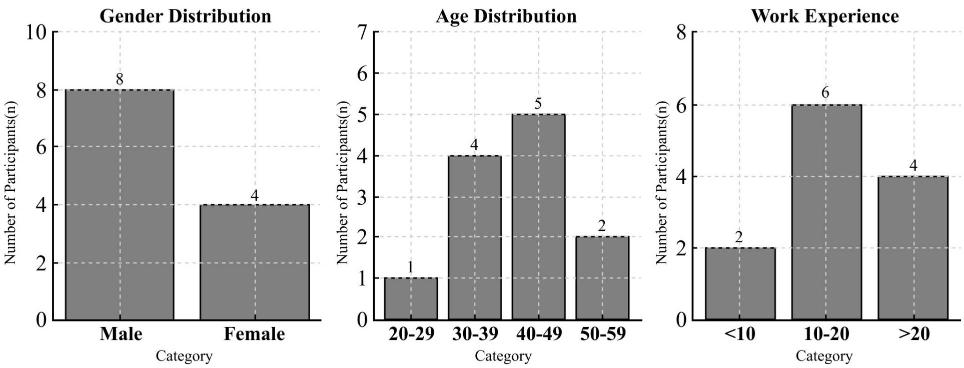

Figure 1: Demographic characteristics of participants.

Additionally, eight representative fishing activities were systematically observed, recording posture, task duration, and environmental parameters (e.g., tidal depth, mud characteristics, weather conditions).

From the integrated data analysis, fishermen's ergonomic needs were categorized into three domains: physiological (knee protection, ankle stability, lumbar support), psychological (occupational dignity, equipment reliability, affordability), and operational (tool storage, portability, environmental adaptability, task assistance). These needs were refined through multiple rounds of expert and industrial designer discussions (Figure 2).

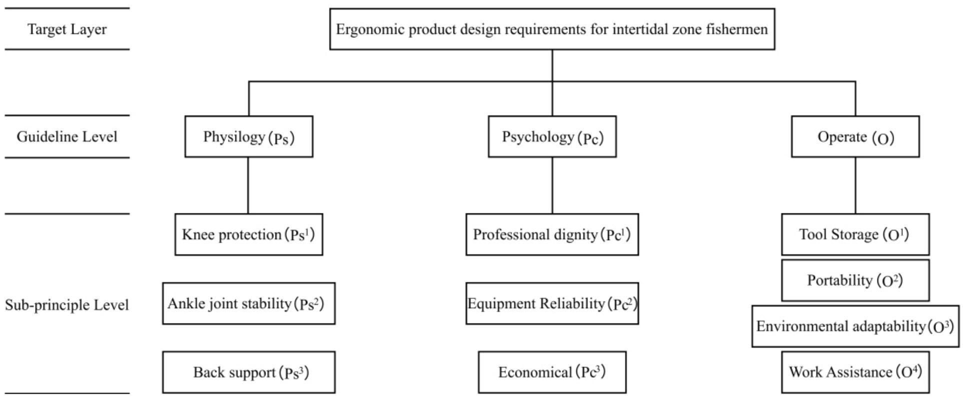

Figure 2: Ergonomic product design requirements for intertidal zone fishermen.

To determine the relative importance of each requirement, AHP was employed. Ten fishermen, two industrial designers, and two fisheries experts participated in constructing pairwise comparison matrices using a 1–9 scale. Consistency ratio ($CR < 0.1$) was used to validate logical coherence. The final AHP weights provided a structured framework for prototype development, ensuring the prioritization of critical ergonomic requirements.

Table 1: Primary indicator judgment matrix and weight.

	Physilogy	Psychology	Operate	Weight
Ps	1	4	2	0.5571
Pc	1/4	1	1/3	0.1226
O	1/2	3	1	0.3202

Table 2: Secondary indicator Ps judgment matrix and weight.

Ps	Ps^1	Ps^2	Ps^3	Weight
Ps^1	1	3	5	0.6333
Ps^2	1/3	1	3	0.2605
Ps^3	1/5	1/3	1	0.1062

Table 3: Secondary indicator Pc judgment matrix and weight.

Pc	Pc^1	Pc^2	Pc^3	Weight
Pc^1	1	1/2	1/3	0.1698
Pc^2	2	1	1	0.3873
Pc^3	3	1	1	0.4429

Table 4: Secondary indicator O judgment matrix and weight.

O	Pc^2	Pc^3	Pc^3	Weight
O^1	1	1/5	3	0.1826
O^2	1	1/3	2	0.1763
O^3	3	1	4	0.5470
O^4	1/2	1/4	1	0.0941

Table 5: Consistency check.

Consistency Ratio	CR^1	CR^2	CR^2	CR^2
Numerical	0.018	0.037	0.018	0.057

PROTOTYPE DEVELOPMENT

Based on AHP findings, the prototype emphasized high-priority needs such as lumbar support and task assistance. The system incorporated:

- Adjustable lumbar support with flexible steel plates for effective spinal protection.
- Human Systems Integration (HSI) is becoming a critical piece of complex Modular storage system with buckle-fastened compartments for tool accessibility.
- Lateral support points compatible with both long- and short-handled tools to reduce operational strain.
- Waterproof lightweight composite materials ensuring durability in wet, saline, and muddy environments.

Figure 3: Physical prototype demonstration.

Prototyping was completed using Rhino software and manufactured via 3D printing and sewing techniques. The prototyping process involved multiple iterative refinements based on feedback from ergonomics experts and target users. printing and sewing techniques.

Figure 4: User experience record (part).

TEST&RESULTS

Prior to field testing, eight intertidal fishermen were recruited from two coastal villages in Jiangsu Province, China. Participants were divided equally into an experimental group (n = 4) and a control group (n = 4). The average age of participants was 42.6 years (range: 31–54), with a mean work experience of 16.8 years. All participants were experienced in clam harvesting and had no reported musculoskeletal disorders at the time of the study. Each participant received RMB 200 (≈USD 28) as compensation.

The experiment was designed to compare ergonomic performance between the developed wearable lumbar support system and conventional fishing equipment. Both groups performed clam collection tasks in similar tidal and environmental conditions. The testing lasted for two consecutive days. On the first day, the control group used conventional tools, while the experimental group used the prototype device. On the second day, the groups switched equipment to minimize individual performance bias. Each task session lasted approximately three hours, during which four categories of data were collected: task efficiency, subjective exertion, safety performance, and user feedback.

Immediately following the field trials, semi-structured interviews were conducted with all participants to gather qualitative feedback regarding comfort, functionality, and perceived fatigue. Interviews lasted 20—30 minutes each and were audio-recorded with participants' consent.

- Task efficiency: The prototype improved work efficiency by 16%, reflected in an 8.2% increase in clam yield and a 12% reduction in task completion time. Yield differences were statistically significant ($p < 0.05$).
- Subjective exertion: Average Borg RPE scores were 11.8 (light to moderate load) with the prototype versus 14.1 (moderate to high load) with baseline equipment, a statistically significant difference of 2.3 points ($p < 0.01$) (Borg, 1998).
- Safety: Slip and fall incidents decreased by 27% with the prototype, equating to 0.5 fewer incidents per trial. Although the difference did not reach statistical significance ($p = 0.07$), the trend suggests enhanced safety. Task errors were reduced by 21%, particularly during long-handled tool operations.
- User feedback: 83% of participants reported improved comfort and praised the lumbar support and tool storage features. However, three participants highlighted cleaning difficulties due to mud adhesion and recommended more washable materials or detachable components.

Additionally, two participants (P3, P6) noted insufficient lightweight design. P3 remarked, “The device still feels heavy during prolonged bending tasks,” while P6 commented, “The uneven weight distribution increases fatigue during load-bearing walking.”

Table 6: Summary of field test results.

Evaluation Metric	Baseline Equipment	Prototype System	Improvement(%)
Clam Yield (kg/h)	5.60	6.06	+8.2%
Task Completion Time (min/task)	25.0	22.0	−12.0%
Borg RPE Score	14.1	11.8	−2.3 ($p < 0.01$)
Comfort Rating (1-5 Likert Scale)	2.8	4.2	+50.0%

DISCUSSION

Field test results largely confirmed the AHP-derived ergonomic priorities. Among the three AHP dimensions—physiological, psychological, and operational—the physiological domain received the highest weighting, particularly the need for lumbar support and postural assistance. This alignment was reflected in the significant reductions in subjective exertion and improved task efficiency observed in the field. The adjustable lumbar module, developed as a direct response to the AHP-derived priorities, effectively minimized spinal strain and fatigue during prolonged bending tasks, validating the design framework.

The operational dimension, which ranked second in the AHP hierarchy, emphasized accessibility and tool management. Positive user feedback on the modular storage system and lateral support points confirmed its practical contribution to workflow continuity and task fluency. Similarly, the psychological dimension—focused on comfort, trust, and occupational dignity—was reflected in participants’ high satisfaction rate (83%), suggesting that ergonomic enhancement can positively affect workers’ sense of professionalism and confidence in challenging environments.

However, post-testing feedback also revealed user concerns that were not fully captured during the AHP evaluation phase. Specifically, participants highlighted difficulties in cleaning mud residues from the surface and perceived the device as insufficiently lightweight for long-duration use. These issues suggest that cleanability, material texture, and weight distribution were underestimated in the original AHP structure, likely because they were not prioritized in the expert-based weighting process. Future AHP iterations could therefore incorporate these usability and maintenance attributes as distinct evaluation criteria to achieve a more holistic ergonomic assessment.

Based on these findings, several directions for prototype refinement are proposed. First, material substitution with hydrophobic or detachable textile components could enhance cleanability in muddy, saline environments. Second, further weight optimization through lightweight composites or modular balancing could reduce cumulative fatigue during load-bearing movement. Finally, integrating feedback from extended user trials and motion-capture analysis may allow quantitative validation of long-term biomechanical benefits.

Overall, this study demonstrates that combining AHP-driven ergonomic prioritization with iterative prototype testing provides an effective pathway for developing user-centered assistive systems. While the prototype achieved measurable improvements in efficiency and fatigue reduction, iterative refinement informed by field experience remains essential to fully address the dynamic and demanding conditions of intertidal labor.

CONCLUSION

This study shows that the lumbar support system improves work efficiency and reduces subjective fatigue among intertidal fishermen. The prototype received positive evaluations in both comfort and functionality, and user feedback revealed further potential for optimization. These findings underscore the importance of ergonomic design in promoting labor sustainability and worker well-being, with potential for broader application in other high-intensity labor sectors.

Nevertheless, limitations include the small sample size (8 participants) and short testing duration, which restrict generalizability. Future research should involve larger samples and incorporate biomechanical measurements (e.g., electromyography, motion capture) to comprehensively validate and optimize design performance.

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