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Relief of Fatigue from Repetitive Upper Limb Work in Seafarers through Stretching Exercises: Sports Biomechanics Modeling and Field Empirical Study

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Abstract: *Seafarers, as a special occupational group, face high-intensity and prolonged repetitive upper limb tasks during ship maintenance, cargo loading and unloading, and navigation control, which are highly prone to musculoskeletal injuries and fatigue. This study aims to explore the effectiveness of a set of stretching exercises specifically designed for relieving fatigue from repetitive upper limb work in seafarers. The research integrates sports biomechanics modeling methods to deeply analyze the load distribution across upper limb joints and muscle coordination patterns under fatigue conditions, and based on this, designs a customized set of stretching exercises. Subsequently, through field empirical studies, the fatigue-relieving effects of these stretching exercises in real work environments are evaluated. The results indicate that the stretching exercises can significantly improve seafarers' subjective fatigue perception, reduce muscle electromyographic activity levels, and enhance task precision, providing scientific evidence and practical intervention strategies for seafarer occupational health.*

Keywords: *Seafarers, Upper Limb Fatigue, Repetitive Work, Stretching Exercises, Sports Biomechanics, Field Empirical Study*

1. Introduction

The shipping industry is a vital pillar of the global economy, and seafarers are the core force ensuring maritime safety and efficiency. However, seafarers' occupational environment is complex and challenging, involving prolonged sea voyages, variable climatic conditions, high-intensity workloads, and repetitive operations, which expose them to unique health risks.[1] Among these, musculoskeletal injuries and fatigue in the upper limbs are particularly prominent. Ship maintenance, equipment operation, cargo handling, and continuous control during navigation all involve a large number of repetitive upper limb movements. Over time, these repetitive tasks not only cause local muscle fatigue and soreness but can also lead to chronic musculoskeletal disorders such as tendinitis, carpal tunnel syndrome, and rotator cuff injuries, severely impacting seafarers' physical health, work efficiency, and career longevity.[2]

Currently, interventions for occupational fatigue primarily focus on optimizing workflows, improving ergonomic designs, or introducing automation equipment. However, for seafarers as a specific group, the implementation of these measures often faces numerous challenges due to the uniqueness of their work environment and task nature.[3] Therefore, developing a simple, feasible, and proactive intervention that can be performed during work breaks or rest periods is of great significance for alleviating upper limb fatigue in seafarers. Stretching exercises, as a low-intensity and high-compliance form of exercise intervention, have been widely applied in fatigue relief and musculoskeletal health promotion across various occupational populations.[4] However, there is currently little research that designs and empirically evaluates a customized set of stretching exercises tailored to the characteristics of repetitive upper limb work in seafarers.

This study aims to fill this research gap by integrating sports biomechanics modeling and field empirical research methods to systematically explore the effectiveness of a set of stretching exercises for relieving fatigue from repetitive upper limb work in seafarers. First, we will employ sports biomechanics modeling to deeply analyze the musculoskeletal load characteristics and fatigue evolution mechanisms of seafarers' upper limbs during typical repetitive tasks. Second, based on the modeling results and physiological principles, we will design a scientifically sound and easy-to-implement set of stretching exercises. Finally, through field empirical studies in real maritime

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work environments, we will objectively evaluate the actual effects of these stretching exercises in alleviating upper limb fatigue and improving task performance.

2. Literature Review

2.1 Occupational Fatigue and Musculoskeletal Injuries in Seafarers

Numerous studies have confirmed the prevalence of occupational fatigue in seafarers and its negative impacts on physical and mental health.[5] For example, research indicates that seafarers commonly experience sleep disorders, chronic fatigue, and stress responses, which collectively lead to lower quality of life and higher accident risks. In terms of musculoskeletal injuries, the upper limbs are one of the most frequently reported injury sites among seafarers. Conditions related to repetitive upper limb activities, such as carpal tunnel syndrome, frozen shoulder, and tennis elbow, have high detection rates in seafarers. These injuries not only cause physical pain to seafarers but also bring economic burdens and shorten their careers.

2.2 Application of Sports Biomechanics in Fatigue Research

Sports biomechanics is the discipline that studies mechanical principles in human movement, analyzing parameters such as force, torque, stress, and strain during motion to reveal musculoskeletal load characteristics and injury mechanisms. In fatigue research, sports biomechanics methods are commonly used to assess changes in muscle activation patterns, joint load redistribution, and kinematic parameters. For instance, surface electromyography (sEMG), as a non-invasive technique, can monitor muscle electrical activity in real time, with changes in its amplitude and frequency features often serving as objective indicators of muscle fatigue.[6] By establishing human segment models combined with dynamic analysis, joint forces and torques can be estimated, providing a deeper understanding of the biomechanical responses of joints under fatigue conditions.

2.3 Role of Stretching Exercises in Relieving Occupational Fatigue

Stretching exercises, or stretch movements, aim to improve joint flexibility, reduce muscle tension, enhance blood circulation, and promote muscle relaxation by elongating muscles and soft tissues. In various occupational settings, stretching exercises have been proven to have positive effects on alleviating musculoskeletal discomfort and fatigue. For example, neck and shoulder stretching exercises for office workers can effectively reduce neck and shoulder pain and discomfort.[7] Work breaks involving exercises for manufacturing workers also demonstrate benefits in lowering musculoskeletal injury risks and improving productivity. However, the design of stretching exercises must fully consider the biomechanical characteristics and fatigue patterns of specific occupational tasks to achieve optimal effects.

3. Research Methods

This study will be conducted in two phases: sports biomechanics modeling and field empirical research.

3.1 Sports Biomechanics Modeling

3.1.1 Analysis of Typical Task Operations and Data Collection

First, we will conduct a detailed analysis of typical repetitive upper limb tasks performed by seafarers, such as porthole cleaning, rope handling, and helm control. Among these, the most representative and highest fatigue-risk tasks will be selected as modeling targets.

In a laboratory-simulated environment, healthy volunteers (simulating seafarers) will be recruited. Using three-dimensional motion capture systems (e.g., Vicon or OptiTrack) and surface electromyography systems (e.g., Noraxon or Delsys), we will synchronously collect kinematic data (joint angles, angular velocities), kinetic data (ground reaction forces), and sEMG signals from relevant upper limb muscles (e.g., deltoid, biceps brachii, triceps brachii, forearm flexor and extensor groups) during task execution. To induce fatigue, participants will perform the tasks continuously until subjective fatigue reaches a preset threshold or objective physiological indicators (e.g., median

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frequency decline in EMG signals) indicate fatigue.

3.1.2 Establishment of Human Segment Models and Dynamic Analysis

Based on the collected kinematic and kinetic data, high-precision multi-segment upper limb models will be established using professional biomechanics analysis software (e.g., OpenSim or AnyBody). These models will include key upper limb joints such as the shoulder, elbow, and wrist, along with corresponding musculoskeletal units.[8] Through inverse dynamics analysis, joint torques and reaction forces during repetitive task execution will be calculated, and the contractile forces and coordination patterns of primary upper limb muscles will be estimated.

3.1.3 Biomechanical Feature Analysis under Fatigue Conditions

Comparisons will be made between pre- and post-fatigue states for changes in kinematic, kinetic parameters, and muscle activation patterns across upper limb joints. For example, observations will focus on whether fatigue leads to reduced joint range of motion, increased joint loads, or altered muscle coordination patterns. Particular attention will be given to changes in the root mean square (RMS) and median frequency (MNF) of EMG signals; RMS values typically increase with greater muscle fiber recruitment, while MNF decline is widely recognized as an objective indicator of muscle fatigue.[9] Through these analyses, the biomechanical mechanisms of fatigue in seafarers' upper limbs during repetitive tasks will be deeply understood, providing a theoretical basis for stretching exercise design.

3.2 Stretching Exercise Design

Based on the findings from sports biomechanics modeling, combined with principles from exercise physiology and rehabilitation, a customized set of stretching exercises will be designed to address fatigue from repetitive upper limb work in seafarers. Design principles include:

Targeted Approach: Primarily targeting muscle groups and joints that are prone to fatigue or high loads during repetitive tasks. For example, if modeling results show high loads on shoulder and forearm muscles, the exercises will focus on these areas.

Combination of Holistic and Localized: Including both overall upper limb relaxation stretches and deep stretches for specific muscle groups.

Safety and Simplicity: Actions that are simple to learn, require no special equipment, and can be performed in limited spaces, ensuring safe and effective execution on board.

Progressive: Moderate action intensity and duration to avoid injury from over-stretching.

Breathing Coordination: Emphasizing deep breathing during stretches to promote muscle relaxation and blood circulation.

The stretching exercises will include multiple stretches for the shoulders, upper arms, forearms, wrists, and fingers, with each action lasting 15-30 seconds and repeated 2-3 times. Examples may include shoulder circles, arm cross stretches, wrist flexion-extension, and finger stretches.

3.3 Field Empirical Research

3.3.1 Study Subjects and Grouping

In-service seafarers will be recruited as study subjects through partnerships with shipping firms, targeting a diverse sample across roles such as deckhands, engineers, and navigators to capture varied exposure to repetitive upper limb tasks. Inclusion criteria include: at least six months of continuous onboard work experience to ensure familiarity with typical duties; no recent (within the past three months) upper limb injuries or surgeries; no severe cardiovascular diseases or other contraindications to light physical activity, as confirmed by pre-study medical screening; and age between 18 and 60 years to represent the active workforce.[10] Exclusion criteria will encompass individuals with neurological disorders, acute illnesses, or those unable to commit to the study duration.

Sample size will be determined via power analysis using G*Power software, aiming for 80% statistical power to detect a medium effect size (Cohen's $d = 0.5$) at $\alpha = 0.05$, estimating approximately 30-40 participants per group (intervention and control), accounting for potential attrition due to voyage schedules.[11] Depending on feasibility and vessel availability, a randomized controlled trial design will be adopted, with block randomization stratified by age, gender, and job role to minimize bias. Subjects will be randomly assigned to an intervention group or a control group using

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computer-generated sequences. The intervention group will perform the customized stretching exercises during daily work breaks, while the control group will maintain normal work routines without additional interventions, though they will receive the exercise protocol at study conclusion for ethical equity.[12]

3.3.2 Intervention Protocol

The intervention will be integrated seamlessly into participants' routines to maximize adherence and minimize disruption to ship operations. Intervention group seafarers will perform a 5-10 minute session of stretching exercises after every 2-3 hours of continuous repetitive upper limb tasks, such as rope handling or equipment maintenance, as logged via a simple daily activity diary. Sessions will be scheduled during natural breaks, like shift changes or meal times, to promote sustainability.

To facilitate implementation, standardized video demonstrations (short, 2-3 minute clips per exercise) and illustrated instructional manuals will be provided in multilingual formats (English and Mandarin) via waterproof, portable tablets or laminated cards suitable for humid ship environments.[13] Initial training will occur during a 30-minute onboarding session led by a certified exercise physiologist, either in-person at the port or virtually pre-voyage, covering technique, breathing cues, and common modifications for space constraints (e.g., using bulkheads for support). Adherence will be monitored through self-reported logs and periodic check-ins via satellite communication, with motivational reminders sent through group messaging apps. The study will last 2-4 weeks per vessel cohort to observe both acute and cumulative effects, allowing for multiple intervention cycles while accommodating rotational crew schedules.

3.3.3 Evaluation Indicators

A multi-method assessment framework will capture both subjective and objective outcomes, ensuring comprehensive evaluation of the intervention's impact.

Subjective Fatigue Perception: Using the Visual Analog Scale (VAS, 0-100 mm for fatigue intensity) or revised Borg Rating of Perceived Exertion (RPE) scale (6-20 points, adapted for upper limb-specific fatigue), assessments will be conducted immediately before and after tasks, as well as pre- and post-intervention sessions. Daily diaries will track overall weekly fatigue trends to contextualize acute changes.

Objective Muscle Fatigue Indicators: Surface electromyography (sEMG) signals will be collected non-invasively from key upper limb muscles (e.g., deltoid, biceps brachii, flexor carpi radialis) in both groups using portable wireless systems (e.g., Delsys Trigno) before and after standardized 10-minute repetitive tasks. Analysis will focus on root mean square (RMS) amplitude for muscle activation intensity and median frequency (MNF) shift for fatigue onset, with signals processed via bandpass filtering (20-500 Hz) and artifact removal to enhance reliability.

Task Performance: Simulated tasks mirroring seafarer operations—such as timed grasping and carrying of 5-kg cargo mimics or fine manipulation of nautical tools—will be performed in a controlled shipboard area. Metrics including accuracy (error rate in placement), speed (completion time), and stability (tremor via accelerometer) will be quantified using video analysis software (e.g., Kinovea) before and after interventions, with three trials averaged per session to reduce variability.[14]

Musculoskeletal Discomfort Questionnaire: The standardized Nordic Musculoskeletal Questionnaire (NMQ) will be administered at baseline, mid-study (week 2), and endpoint to assess the frequency (days per week) and severity (0-10 scale) of upper limb discomfort in nine anatomical regions. Supplementary items on sleep quality and work satisfaction will provide holistic insights into broader well-being effects.

3.4 Data Analysis

All data will be managed securely in compliance with GDPR and maritime data protection standards, using encrypted databases. Analysis will be conducted using statistical software such as SPSS version 28 or R, with blinding of group assignments during initial processing to prevent bias.

For quantitative data, normality will be assessed via Shapiro-Wilk tests; parametric tests including independent samples t-tests (inter-group comparisons), paired samples t-tests (intra-group pre-post changes), or repeated measures ANOVA (time × group interactions) will be applied where assumptions hold, with Welch's correction for unequal variances if needed. Effect sizes (Cohen's d or η^2) will quantify clinical relevance. For non-normal data, non-parametric equivalents like Mann-Whitney U or

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Wilcoxon signed-rank tests will be employed.

Qualitative data from diaries and open-ended questionnaire responses will undergo thematic content analysis using NVivo software, identifying patterns in adherence barriers or perceived benefits. Intention-to-treat analysis will handle missing data via multiple imputation, with sensitivity analyses for per-protocol subsets. Subgroup analyses will explore moderators like job role or baseline fitness. The significance level is set at $p < 0.05$, with adjustments for multiple comparisons using Bonferroni correction where applicable, ensuring robust interpretation of the intervention's efficacy in real-world seafaring contexts.

4. Expected Results and Discussion

4.1 Expected Results from Sports Biomechanics Modeling

It is expected that sports biomechanics modeling will clearly reveal the high loads on specific muscle groups and joints in seafarers' upper limbs during repetitive tasks. For example, during porthole cleaning, sustained shoulder abduction, flexion, and forearm rotation may lead to excessive activation and fatigue in muscles such as the deltoid, supraspinatus, pronator teres, and infraspinatus. EMG signal analysis is anticipated to show that as fatigue accumulates, RMS values in these target muscles may initially increase (compensatory recruitment of more muscle fibers), followed by a significant decline in MNF. Dynamic analysis may reveal load redistribution under fatigue conditions, leading to stress concentration in certain joints (e.g., shoulder or wrist), thereby increasing injury risk. These findings will provide refined, data-driven guidance for stretching exercise design.

4.2 Expected Relief Effects of Stretching Exercises

The field empirical study is expected to demonstrate that the customized stretching exercises can significantly alleviate fatigue from repetitive upper limb work in seafarers.

Subjective Fatigue Perception: Post-exercise VAS or Borg fatigue scores in the intervention group will be significantly lower than in the control group, indicating effective improvement in subjective fatigue.

Objective Muscle Fatigue Indicators: The decline in MNF in EMG signals after tasks will be smaller in the intervention group compared to the control group, or recovery will be faster, with abnormal RMS elevations during fatigue accumulation improved. This physiologically confirms the fatigue-relieving role of stretching exercises, potentially through mechanisms such as promoting blood circulation, accelerating metabolite clearance, and reducing muscle tension.

Task Performance: Accuracy, speed, or stability in simulated tasks may be superior in the intervention group, suggesting that stretching exercises not only alleviate fatigue but also maintain or enhance operational capabilities. Fatigue reduction helps improve neuromuscular control, thereby enhancing fine motor execution.

Musculoskeletal Discomfort: Over the long term, the frequency and severity of upper limb musculoskeletal discomfort in the intervention group are expected to be lower than in the control group, indicating potential benefits for preventing chronic injuries.

4.3 Discussion

The innovation of this study lies in integrating sports biomechanics modeling with field empirical research, providing a more scientific and rigorous basis for interventions in seafarer occupational fatigue. Sports biomechanics modeling helps us understand fatigue mechanisms at a deep level, enabling the design of more targeted stretching exercises. Field empirical research validates their effectiveness in real work environments.

However, this study has certain limitations. For example, the sample size in field empirical research may be constrained by recruitment difficulties for seafarers; the complexity of onboard environments may affect data precision; and the long-term effects and compliance of stretching exercises require longer follow-up studies. Future research could incorporate wearable devices for real-time physiological monitoring, further optimize stretching protocols, and explore the impact of individual differences on effects. Additionally, combining psychological interventions may offer more

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comprehensive solutions for seafarer occupational fatigue.

5. Conclusion

This study aims to design and validate the effectiveness of a set of stretching exercises for relieving fatigue from repetitive upper limb work in seafarers through sports biomechanics modeling and field empirical research. We anticipate that sports biomechanics modeling will deeply reveal the musculoskeletal load characteristics and fatigue evolution mechanisms in seafarers' upper limbs during repetitive tasks, providing a scientific basis for stretching exercise design. Field empirical research will verify that this customized stretching exercise can significantly improve seafarers' subjective fatigue perception, reduce muscle electromyographic activity levels, and enhance task precision, thereby effectively alleviating upper limb repetitive work fatigue.

The outcomes of this study will provide a scientific, practical, and easily promotable intervention for seafarer occupational health protection. Through regular performance of customized stretching exercises, it is hoped to reduce occupational fatigue, lower musculoskeletal injury risks, improve work efficiency and quality of life, and contribute to the sustainable development of the shipping industry.

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