Textile & Leather Review

ISSN 2623-6281| www.tlr-journal.com | 10.31881/TLR

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How to cite: Sun M, Zhao M. Design and Biomechanical Performance Evaluation of Functional Martial Arts Training Clothing. Textile & Leather Review. 2026; 9:2106-2123. https://doi.org/10.31881/TLR.2026.2106

How to link: https://doi.org/10.31881/TLR.2026.2106

Published: 25 April 2026

Design and Biomechanical Performance Evaluation of Functional Martial Arts Training Clothing

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Article

https://doi.org/10.31881/TLR.2026.2106

Published 25 April 2026

ABSTRACT

Martial arts training requires garments capable of accommodating large-amplitude, multi-planar movements, yet quantitative evaluation of garment structural effects remains limited in textile engineering research. This study proposes a biomechanics-informed design and evaluation approach for functional martial arts training clothing and reports a pilot experimental assessment. A functional garment incorporating targeted panel segmentation, directional elasticity, and localized structural features was developed based on movement demand analysis. Sixteen experienced practitioners performed representative training tasks under functional and conventional clothing conditions. Lower-limb joint range of motion (ROM) was quantified using three-dimensional inertial motion capture. The results revealed movement- and plane-specific differences in joint ROM between clothing conditions, indicating that garment structural design can influence clothing–movement interaction and joint kinematic responses in high-mobility training applications.

KEYWORDS

functional clothing design, biomechanics-informed design, joint range of motion, inertial motion capture

INTRODUCTION

Martial arts training is characterized by complex movement patterns involving large-amplitude joint excursions, rapid transitions between postures, and coordinated actions of the upper and lower limbs. Representative training movements such as deep stances, high kicks, rotational stepping, and explosive strikes impose substantial biomechanical demands on joint mobility, movement continuity, and postural control demands [1-3]. The effectiveness and safety of such training therefore depend not only on practitioners' physical capabilities, but also on external factors that may facilitate or constrain natural movement execution.

Training clothing constitutes an external interface between the body and the environment and can act as a mechanical constraint on human motion. While martial arts training garments are traditionally designed with emphasis on cultural symbolism, visual expression, and standardized silhouettes, their structural configuration—such as panel layout, seam placement, material stretch orientation, and local reinforcement—may substantially influence joint kinematics during dynamic movements. Inadequate alignment between garment structure and movement demands can introduce unintended resistance, restrict joint range of motion, and disrupt movement fluency, potentially affecting training quality and increasing physical strain [4,5].

From a biomechanical perspective, clothing-induced movement restriction has been widely recognized in studies of protective equipment and functional apparel. Previous research has demonstrated that garment weight, bulkiness, and material stiffness can alter gait patterns, shift centers of mass, and limit joint mobility, leading to increased metabolic cost and musculoskeletal stress [6-8]. These findings indicate that clothing should be regarded not merely as a passive covering, but as an active mechanical system interacting with the human musculoskeletal system. However, most existing investigations focus on industrial protective clothing or general sportswear, with limited attention paid to discipline-specific training scenarios that involve extreme ranges of motion and highly coordinated actions.

Martial arts training presents a distinctive biomechanical context that differs fundamentally from conventional locomotion or cyclic athletic activities. Unlike walking or running, martial arts movements frequently require simultaneous large joint excursions across multiple anatomical planes, rapid acceleration–deceleration cycles, and asymmetric postural demands [2,9]. Consequently, training garments designed according to generic sportswear principles may fail to accommodate these specialized movement requirements. Despite the prevalence of martial arts practice worldwide, quantitative evidence linking martial arts training clothing design to biomechanical performance remains scarce, and the extent to which garment structure influences movement execution during training has not been systematically examined.

A critical limitation of existing studies on functional apparel lies in the lack of direct validation between garment structural design and objective biomechanical outcomes. While improvements in comfort or perceived mobility are often reported, fewer studies establish measurable relationships between specific design features and changes in joint kinematics [4,5]. Without such evidence, functional training clothing design risks remaining intuitive rather than evidence-based. Addressing this gap requires the adoption of objective biomechanical metrics capable of capturing clothing-induced movement constraints under controlled experimental conditions.

Joint range of motion (ROM) has been widely employed as an indicator of movement restriction induced by external equipment or clothing systems and is therefore suitable for evaluating clothing–movement interaction in functional apparel contexts [4,5,7]. As martial arts training relies heavily on large and coordinated joint movements, ROM provides a suitable and interpretable metric for evaluating the biomechanical impact of training clothing on movement performance.

Accordingly, the present study aims to design a functional martial arts training garment informed by biomechanical movement requirements and to quantitatively evaluate its biomechanical effects using objective motion analysis. By comparing joint range of motion (ROM) during representative martial arts movements under functional and conventional clothing conditions, this study seeks to examine whether biomechanics-informed structural design can reduce clothing-induced movement constraints.

To address this objective, a biomechanics-informed design–evaluation framework is adopted to guide garment development and experimental assessment. A pilot experimental investigation is conducted to explore the feasibility and biomechanical implications of functional martial arts training clothing. The overall research framework is illustrated in Figure 1.

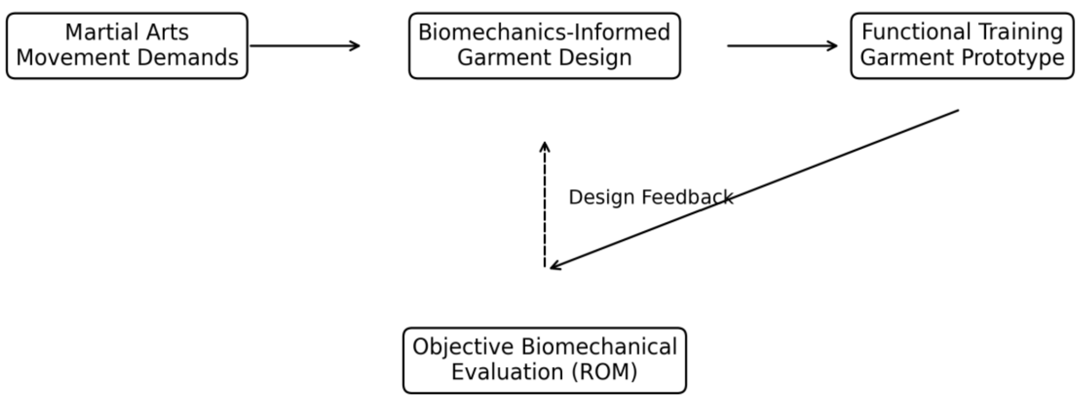

Figure 1. Design–evaluation framework for functional martial arts training clothing

The framework illustrates the workflow from martial arts movement demands to biomechanics-informed garment design and prototype development, followed by objective biomechanical evaluation based on joint range of motion (ROM). Evaluation outcomes provide feedback for iterative design refinement.

METHODOLOGY

Participants

A total of sixteen experienced martial arts practitioners (10 male, 6 female) participated in this pilot study (age: 26.8 ± 4.9 years; height: 172.6 ± 6.8 cm; mass: 68.9 ± 8.7 kg). All participants had a minimum of five years of continuous martial arts training experience and were actively training at the time of data collection. All participants were right-leg dominant for kicking-related movements.

This sample size was selected to support a pilot-level, within-subject biomechanical investigation, intended to examine feasibility and identify consistent kinematic trends rather than to provide population-level inference. No participants reported musculoskeletal injury in the six months prior to testing that could affect lower-limb movement performance.

All participants provided written informed consent, and experimental procedures complied with institutional ethical guidelines and the Declaration of Helsinki.

Garment Conditions and Design Rationale

Experimental Clothing Conditions

Two clothing conditions were evaluated in this study:

Conventional martial arts training clothing (CMC): a commonly used loose-fitting training uniform composed of a woven polyester–cotton fabric, representative of attire typically worn during routine martial arts practice.

Functional martial arts training clothing (FMTC): a prototype garment developed based on biomechanical movement requirements, incorporating optimized panel segmentation, directional elasticity, and localized structural reinforcement.The elastic materials used in the FMTC were intentionally integrated as part of the overall structural configuration rather than treated as an isolated experimental variable.

To minimize potential psychological bias associated with garment perception, the two clothing conditions were designed to be comparable in overall appearance and mass (CMC: 0.62 ± 0.05 kg; FMTC: 0.65 ± 0.06 kg).

Biomechanics-Informed Design Considerations

The functional garment was developed following an analysis of representative martial arts movements characterized by large joint excursions, rapid directional changes, and coordinated multi-planar motion. From a biomechanical perspective, clothing can act as a mechanical constraint on movement, and inappropriate structural design may restrict joint excursion and alter movement patterns [4,5]. Based on these considerations, the garment design incorporated the following principles:

High-mobility zone identification, particularly around the hip, knee, and lumbopelvic regions, where substantial angular displacement frequently occurs during martial arts training movements.

Alignment of fabric elasticity with dominant joint movement directions, aiming to reduce mechanical resistance during flexion, extension, and rotational motions, which has been shown to influence joint kinematics in functional apparel contexts [4,7].

Optimized seam placement and panel geometry, intended to prevent fabric accumulation and localized constraint during deep stances and high-kicking actions.

Localized fit-support zones, designed to improve garment fit and movement consistency without restricting joint range of motion.

These design features were integrated to reduce clothing-induced movement constraints while maintaining sufficient structural durability for repeated training use.

To clarify the translation from movement demand analysis to garment structure, representative martial arts movements were explicitly mapped to corresponding design strategies.

High front kicking movements, characterized by large sagittal-plane hip flexion and knee extension, informed the placement of high-elasticity panels and seam orientations aligned with flexion–extension directions in the hip and thigh regions to reduce resistance during rapid joint excursion.

Deep horse stance postures, involving sustained lower-limb flexion, guided the optimization of panel geometry and seam configuration to minimize fabric accumulation and localized constraint during prolonged flexed positions.

Rotational stepping movements, emphasizing transverse-plane rotation, informed the incorporation of directional elasticity and panel segmentation around the lumbopelvic region to accommodate rotational joint excursion while maintaining garment fit.

Motion Capture System and Biomechanical Measurements

Kinematic data were collected using a three-dimensional inertial motion capture system (Xsens MVN, Xsens Technologies B.V., The Netherlands), consisting of 17 wireless inertial measurement units (IMUs) distributed across major body segments. Each sensor recorded segment orientation and angular velocity, enabling reconstruction of full-body joint kinematics.

Joint range of motion (ROM) was selected as the primary biomechanical outcome measure, as it directly reflects the extent of joint excursion and potential movement restriction induced by clothing. ROM was defined as the total angular displacement of a joint during a movement cycle and calculated as the difference between the maximum and minimum joint angles observed within each trial.

ROM analysis focused on the hip, knee, and ankle joints of the dominant lower limb, which play a critical role in martial arts techniques involving kicking, stance transitions, and rotational demands. Joint angles were resolved in the sagittal, frontal, and transverse planes according to standard biomechanical conventions. Motion data were sampled at 120 Hz, which is sufficient to capture the rapid joint movements characteristic of martial arts training tasks.

Experimental Tasks and Movement Standardization

Participants performed three representative martial arts training movements selected to reflect distinct biomechanical demands commonly encountered during routine practice:

High front kick, emphasizing rapid sagittal-plane hip flexion and knee extension;

Deep horse stance, emphasizing sustained lower-limb flexion and postural demands;

Rotational stepping movement, emphasizing transverse-plane rotational demands and coordination.

To enhance execution consistency across trials and clothing conditions while preserving ecological validity, explicit standardization criteria were applied. For the high front kick, participants were instructed to reach a target height aligned with the ipsilateral iliac crest, indicated by an adjustable visual marker. Kicking cadence was controlled using a metronome (1.2–1.5 s per kick cycle). Trials in which the target height was not reached or cadence deviated by more than ±10% were excluded.The target height aligned with the iliac crest was used to standardize task execution across trials and clothing conditions rather than to elicit maximal joint range of motion. Accordingly, the measured ROM represents task-constrained joint excursion under controlled movement requirements.

For the deep horse stance, participants maintained the posture for 5 s per trial. Knee flexion depth was visually verified by the experimenter to ensure consistency across repetitions, and trials with visible posture drift were excluded.

For the rotational stepping movement, step length was standardized to approximately shoulder width, rotation direction was predefined, and the movement was completed within a 2 s cadence guided by a metronome. Trials exhibiting loss of balance or incomplete rotation were discarded.

Each movement was performed under both clothing conditions using a randomized crossover design. Three valid trials per condition were retained for analysis. Rest intervals of 60–90 s were provided between trials to minimize fatigue effects.

Data Processing and Statistical Analysis

Data Preprocessing

Raw kinematic data were visually inspected to identify signal artifacts, sensor dropouts, or execution errors. Trials with incomplete recordings or deviations from the predefined execution criteria were excluded from further analysis. For each participant and clothing condition, joint range of motion (ROM) values were calculated for each valid trial and subsequently averaged across the three trials per movement to obtain representative measures. This averaging procedure was applied to reduce intra-participant variability while preserving systematic differences between clothing conditions.

Statistical Analysis

Statistical analyses were conducted using SPSS (Version 26.0, IBM Corp., USA). The experimental design followed a within-subject repeated-measures framework, with clothing condition (conventional martial arts clothing, CMC, vs. functional martial arts training clothing, FMTC) treated as the primary factor. As the comparison involved two levels of the repeated factor, paired-sample t-tests were employed as the statistical implementation of the repeated-measures analysis for each joint, movement, and anatomical plane.

Normality of ROM distributions was assessed using the Shapiro–Wilk test prior to inferential analysis. In addition to p-values, effect sizes (Cohen's d for paired designs) and 95% confidence intervals (CI) for mean differences were calculated to quantify the magnitude and precision of observed effects. Given the exploratory, pilot nature of this study, the primary analytical objective was to identify consistent, task-dependent kinematic trends associated with clothing condition rather than to establish definitive population-level inference. Therefore, no formal correction for multiple comparisons (e.g., Bonferroni adjustment) were not applied, as such corrections may substantially increase the risk of Type II error in small-sample pilot studies. Instead, interpretation emphasized the directionality, consistency, and magnitude of condition-related differences across joints, planes, and movements, with effect sizes and confidence intervals considered alongside p-values to mitigate the risk of Type I error. Statistical significance was set at $p < 0.05$.

RESULTS

Joint ROM in the Sagittal Plane During Martial Arts Movements

Significant effects of clothing condition on joint range of motion (ROM) were observed in the sagittal plane across the representative martial arts movements. Overall, sagittal-plane ROM at the hip and knee joints differed consistently between the functional martial arts training clothing (FMTC) and the conventional martial arts clothing (CMC), while inter-individual variability remained within an acceptable range for a pilot-level analysis. A visual comparison of representative joint ROM outcomes between clothing conditions is provided in Figure 2.

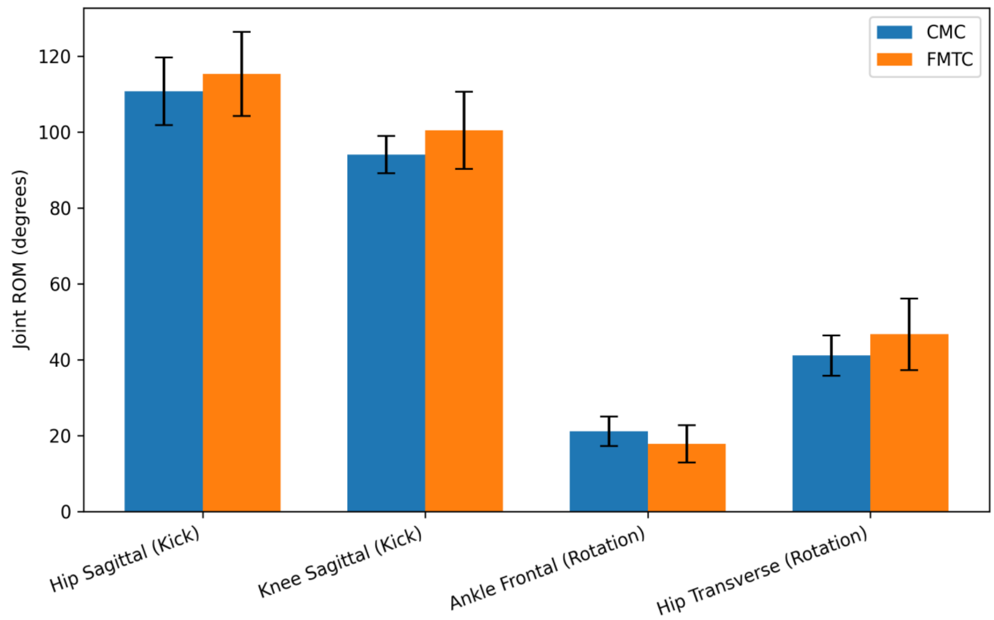

Figure 2. Comparison of joint range of motion (ROM) between conventional martial arts clothing (CMC) and functional martial arts training clothing (FMTC)

Bars represent mean values, and error bars indicate standard deviation (SD). Representative ROM differences are shown across sagittal-, frontal-, and transversal-plane movements. Detailed statistical results are reported in Tables 1–3.

Table 1 summarizes sagittal-plane joint ROM under the two clothing conditions.

Table 1. Sagittal-plane joint ROM (mean ± SD) under different clothing conditions

Movement	Joint	CMC (°)	FMTC (°)	Mean diff (°)	95% CI (°)	p	Cohen's d
High front kick	Hip flexion	110.8 ± 8.9	115.3 ± 11.1	+4.4	[1.1, 7.7]	0.019	0.66
	Knee excursion	94.1 ± 4.9	100.5 ± 10.2	+6.4	[2.1, 10.7]	0.006	0.79
Deep horse stance	Hip flexion	78.2 ± 6.8	79.0 ± 7.8	+0.8	[−1.6, 3.2]	0.496	0.17
	Knee flexion	103.1 ± 8.1	103.8 ± 9.0	+0.7	[−1.7, 3.1]	0.540	0.16

Abbreviations: CMC, conventional martial arts clothing; FMTC, functional martial arts training clothing; CI, confidence interval. Mean differences are calculated as FMTC–CMC.

During the high front kick, participants wearing the FMTC condition demonstrated significantly greater sagittal-plane hip flexion ROM and knee joint excursion compared with the CMC condition (Table 1). These differences were most evident during the peak kicking phase, which requires large-amplitude flexion–extension movements to achieve effective limb acceleration. The observed increases in hip and knee ROM under the FMTC condition indicate reduced clothing-induced mechanical resistance during rapid sagittal-plane joint excursions.

In contrast, during the deep horse stance, which involves sustained lower-limb flexion rather than rapid joint motion, sagittal-plane ROM at the hip and knee joints showed only small and non-significant differences between clothing conditions. Although the absolute ROM magnitude did not markedly increase under the FMTC condition, joint excursion values showed less visually apparent trial-to-trial variation compared with the CMC condition, suggesting altered accommodation of prolonged flexed postures without promoting excessive joint motion.

Across all sagittal-plane–dominant movements, the FMTC condition did not result in excessive increases in joint ROM. Instead, sagittal-plane joint excursions more closely reflected the movement-specific amplitude characteristics of the tasks, indicating that the functional garment facilitated natural joint motion without inducing compensatory overextension.

Joint ROM in the Frontal Plane

In the frontal plane, the effects of clothing condition on joint ROM were more localized and joint-specific. No statistically significant differences were detected at the hip joint for any of the tested movements. However, condition-related differences were observed at the knee and ankle joints, particularly during movements involving unilateral support and dynamic weight transfer.

Frontal-plane ROM results are presented in Table 2.

Table 2. Frontal-plane joint ROM (mean ± SD) under different clothing conditions

Movement	Joint	CMC (°)	FMTC (°)	Mean diff (°)	95% CI (°)	p	Cohen's d
Rotational stepping	Ankle inversion–eversion	21.1 ± 3.9	17.8 ± 4.9	−3.3	[−5.4, −1.2]	0.002	0.93
High front kick (landing phase)	Knee abduction–adduction	13.1 ± 2.7	11.5 ± 3.2	−1.6	[−2.7, −0.5]	0.007	0.78

During the rotational stepping movement, the CMC condition was associated with larger frontal-plane ankle inversion–eversion ROM compared with the FMTC condition, reflecting greater medial–lateral joint excursion during the support phase. Under the FMTC condition, frontal-plane ankle ROM was lower, while task execution remained qualitatively comparable across conditions.

Similarly, during the landing and stabilization phase of the high front kick, frontal-plane knee abduction–adduction ROM was lower under the FMTC condition than under the CMC condition. These differences indicate condition-associated modulation of frontal-plane joint excursion magnitude at the knee during rapid transition phases.

Importantly, the FMTC condition did not eliminate frontal-plane joint motion at either the knee or ankle. Rather, the observed differences reflect changes in joint excursion patterns between clothing conditions within the same task and measurement context. As kinetic and neuromuscular measures were not collected, the present findings should be interpreted as kinematic differences rather than direct evidence of altered kinematic modulation or protective mechanisms.

Joint ROM in the Transversal Plane During Rotational Movements

Distinct clothing-related effects were observed in the transversal plane, particularly during movements emphasizing rotational demands.. Differences in rotational joint ROM between clothing conditions were most pronounced at the hip joint, whereas distal joints exhibited more limited changes.

Transversal-plane ROM during the rotational stepping movement is summarized in Table 3.

Table 3. Transversal-plane joint ROM (mean ± SD) under different clothing conditions

Joint	CMC (°)	FMTC (°)	Mean diff (°)	95% CI (°)	p	Cohen's d
Hip rotation	41.1 ± 5.3	46.7 ± 9.4	+5.7	[2.0, 9.4]	0.005	0.83
Knee rotation	18.4 ± 5.2	19.3 ± 5.6	+0.9	[−0.6, 2.4]	0.195	0.34
Ankle rotation	10.7 ± 3.3	10.4 ± 4.0	−0.3	[−1.4, 0.8]	0.572	0.14

During the rotational stepping movement, participants wearing the FMTC condition demonstrated significantly greater hip rotational ROM compared with the CMC condition. This finding indicates that the functional garment was associated with increased rotational joint excursion at the proximal joint under the current task conditions, where rotational motion is primarily generated during martial arts techniques.

At the knee joint, transversal-plane ROM under the FMTC condition was slightly greater than that observed under the CMC condition; however, this difference did not reach statistical significance. The modest magnitude of change suggests that rotational joint excursion at the knee was not substantially altered between clothing conditions.

Similarly, ankle rotational ROM remained statistically comparable between the FMTC and CMC conditions. The absence of significant differences at distal joints indicates that the observed increase in hip rotational ROM was not accompanied by detectable increases in knee or ankle rotational excursion within the resolution of the present measurement approach.

Across the three anatomical planes, the functional martial arts training clothing demonstrated a consistent and movement-specific pattern of kinematic influence. In the sagittal plane, the FMTC condition was associated with greater joint excursions during high-mobility movements, while not producing substantial changes in joint ROM during sustained postures. In the frontal plane, condition-associated differences in lateral joint excursion magnitude were observed at the knee and ankle during movements involving unilateral support. In the transversal plane, increased rotational ROM was observed at the hip without corresponding changes at distal joints.

Collectively, these findings suggest that biomechanics-informed garment design is associated with movement- and plane-specific differences in joint kinematics that correspond to the functional demands of martial arts training movements at a pilot study scale.

DISCUSSION

Interpretation of Sagittal-Plane ROM Changes

The present study examined the biomechanical implications of functional martial arts training clothing using joint range of motion (ROM) as an objective indicator of clothing–movement interaction. In the sagittal plane, the results indicate that the functional martial arts training clothing (FMTC) facilitated joint excursions that more closely matched the amplitude demands of representative martial arts movements, particularly during high-mobility tasks such as the high front kick.

Unlike conventional loose-fitting garments, which may introduce unintended resistance during rapid flexion–extension movements, the FMTC condition was associated with increased hip and knee ROM during dynamic kicking actions. Importantly, this increase should not be interpreted as excessive joint motion, but rather as a reduction in clothing-induced constraint that allows joint excursion to more closely reflect the kinematic requirements of the task. Similar interpretations have been reported in studies of functional and protective clothing, where increased sagittal-plane ROM reflects accommodation of task-specific movement demands rather than overextension or instability [4,5].

During the deep horse stance, the FMTC condition did not substantially alter absolute sagittal-plane ROM magnitude but appeared to exhibit less visually apparent variability in joint excursion across repeated trials, although variability was not formally quantified in the present analysis. This finding suggests that the effects of the functional garment extend beyond peak movement amplitude and include altered kinematic behavior during sustained postures. Comparable observations have been reported in studies examining the interaction between garment structure and prolonged lower-limb loading tasks [10].

Frontal-Plane ROM and Frontal-Plane Joint Excursion Characteristics

In the frontal plane, the functional garment was associated with differences in joint ROM at the ankle and knee during movements involving unilateral support and rapid weight transfer. Compared with the conventional garment, the FMTC condition exhibited reduced medial–lateral joint excursion magnitude while maintaining sufficient freedom for task execution.

From a biomechanical perspective, larger frontal-plane joint excursions have been associated in prior studies with altered joint motion characteristics and increased mechanical demands at the joint, particularly at the ankle joint. Specifically, increased inversion–eversion ROM during dynamic tasks has been reported to be associated with altered joint motion patterns and increased lower-limb injury susceptibility [7,8]. However, the present findings should be interpreted as condition-associated kinematic modulation rather than direct evidence of altered joint motion characteristics or injury risk.

The observed differences in frontal-plane joint excursion under the FMTC condition suggest that garment structural features, such as localized fit and directional elasticity, may influence lateral joint motion patterns during dynamic tasks. These effects should be interpreted as kinematic differences between clothing conditions within the current measurement and task context, rather than definitive indications of stabilization or protective mechanisms.

Transversal-Plane ROM and Rotational Joint Excursion

Martial arts techniques frequently rely on coordinated rotational movements of the trunk and lower limbs to facilitate rapid directional changes. In the transversal plane, the FMTC condition was associated with greater hip rotational ROM during rotational stepping movements, indicating increased rotational joint excursion at the proximal joint under the current task conditions.

Notably, this increase in hip rotational ROM was not accompanied by statistically significant changes in rotational ROM at the knee or ankle joints. This pattern indicates that the observed kinematic differences between clothing conditions were primarily expressed at the hip within the resolution of the present measurement approach. Without kinetic or neuromuscular data, no conclusions can be drawn regarding load redistribution or protective mechanisms along the kinetic chain.

In contrast, conventional garment structures may restrict rotational freedom at the proximal joint, potentially influencing how rotational motion is expressed during complex martial arts movements. Although kinetic outcomes were not directly assessed in the present study, the observed kinematic differences suggest that garment structure can affect the joint-level expression of rotational motion during training tasks.

Implications for Functional Garment Design in Martial Arts

Overall, this pilot study indicates that functional martial arts training clothing is associated with movement- and plane-specific differences in joint kinematics. Rather than uniformly increasing or restricting joint motion, the FMTC condition exhibited differentiated kinematic responses across anatomical planes.

From a design perspective, these results support the relevance of targeted panel segmentation, directional elasticity, and localized fit strategies in influencing clothing–movement interaction. Similar design philosophies have been applied in functional sportswear and protective apparel contexts, where biomechanics-informed structural decisions are associated with altered movement characteristics [4,6]. Comparable findings have been reported in studies of occupational and protective clothing, where garment design and mass distribution were shown to influence movement characteristics and physiological responses during task execution [11].

Limitations and Future Work

Several limitations of the present study should be acknowledged. First, the sample size was intentionally limited to support a pilot-level evaluation, and the findings should therefore be interpreted as exploratory rather than definitive. Second, the analysis focused exclusively on joint range of motion (ROM) and did not incorporate kinetic or neuromuscular measures, which may provide additional insight into performance-related and injury-relevant mechanisms. In addition, the use of a predefined target height during the kicking task may have introduced a ceiling effect on absolute ROM values; however, as both clothing conditions were tested under identical task constraints, the comparison reflects relative, task-constrained differences in clothing-induced joint excursion rather than maximal joint mobility. Moreover, although inertial motion capture systems have demonstrated acceptable validity for lower-limb kinematic analysis, particularly in the sagittal plane, frontal- and transversal-plane differences of small magnitude should be interpreted as relative, condition-dependent changes rather than precise absolute joint angle differences. Finally, the combination of a limited sample size and multiple statistical comparisons increases the possibility of Type I error, and the reported p-values should therefore be interpreted cautiously in conjunction with effect sizes and confidence intervals.

Future studies should expand the participant pool, include additional biomechanical metrics such as joint moments and muscle activation patterns, and examine a broader range of martial arts techniques. The use of validated inertial motion capture systems in sport-specific movements has been shown to provide reliable kinematic data and may support such extensions [12,13].

Summary of Key Findings

In summary, this study identifies movement- and plane-specific differences in joint kinematics associated with biomechanics-informed martial arts training clothing. By being associated with reduced clothing-induced constraints and condition-associated joint excursion patterns across multiple anatomical planes, functional garment design may support evidence-based development of specialized training apparel for high-mobility martial arts applications.

CONCLUSION

This study proposed and preliminarily examined a biomechanics-informed functional martial arts training garment through an integrated design–evaluation framework. By combining garment structural design with objective kinematic assessment, the research addressed a methodological gap between experience-driven apparel development and quantitative evaluation of clothing–movement interaction in martial arts training contexts.

The findings indicate that training clothing can function as a mechanical interface that measurably influences joint kinematics during martial arts movements. Compared with conventional training garments, the functional garment was associated with condition-related differences in joint excursion patterns across multiple anatomical planes. Specifically, greater joint excursions were observed in task-relevant anatomical planes, while differences in excursion magnitude were identified in planes associated with lateral motion, reflecting a differentiated kinematic response rather than a uniform increase in joint motion. From a design and engineering perspective, the results support the potential relevance of region-specific structural strategies, including targeted panel segmentation, directional elasticity, and localized fit features, in shaping clothing–movement interaction. These structural characteristics were associated with reduced clothing-induced kinematic constraints during large-amplitude and multi-planar movement tasks without increasing garment mass or introducing rigid elements, highlighting the importance of aligning garment structure with task-specific biomechanical characteristics to minimize clothing-induced movement interference.

As this investigation was conducted as a pilot study with a limited sample size, the findings should be interpreted as preliminary. Nevertheless, the observed kinematic trends provide empirical support for the feasibility of biomechanics-informed design approaches in martial arts training clothing. Future research incorporating larger participant cohorts, additional biomechanical metrics, and a broader range of training movements will be necessary to further elucidate the biomechanical characteristics and kinematic implications of garment–movement interaction.

Overall, this study contributes a reproducible methodological framework and initial empirical evidence to functional apparel engineering, offering design-oriented insights for the development of specialized training garments informed by the biomechanical characteristics of representative martial arts training tasks.

Author Contributions

Meng Sun and Miao Zhao designed the study; all authors conducted the study; Meng Sun and Miao Zhao collected and analyzed the data. Meng Sun and Miao Zhao participated in drafting the manuscript, and all authors contributed to critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, took public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work were appropriately investigated and resolved.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

Ethics Approval and Consent to Participate

This survey was conducted in compliance with Ethics Committee of Shandong Business Institute. Participants were informed of the study's purpose and data usage prior to participation, and responses were collected anonymously. No personally identifiable information was stored.

Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

Acknowledgements

Not applicable.

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