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Effects of Fatigue and Cognitive Load on Knee Kinematics and Mechanical Loading During Backhand Forecourt Lunges in Highly Trained Male Badminton Players

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Article

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Abstract

Background

This study examined whether fatigue modifies the effects of cognitive load on knee kinematics and mechanical loading during backhand forecourt lunges in badminton.

Methods

Twenty highly trained male Tier 3 badminton players performed backhand forecourt lunges without cognitive load and with cognitive load. Both conditions were tested before and after fatigue. Cognitive load was imposed using a sport-specific spatial Simon task, and fatigue was induced through full-court multidirectional shuttle footwork. Three-dimensional kinematics and ground reaction forces were recorded synchronously. Analysis focused on the weight-acceptance phase from initial contact to maximum knee flexion.

Results

Significant fatigue × cognitive load interactions were observed for peak knee flexion angle, sagittal range of motion, and weight-acceptance duration. Interactions were also significant for peak knee abduction moment, peak mediolateral ground reaction force, and load rate (p = 0.004–0.032, η_p^2=0.219–0.363). Simple-effects analyses indicated that, under cognitive load, peak knee flexion angle and sagittal range of motion decreased after fatigue, and weight-acceptance duration shortened. Peak knee abduction moment load rate, and peak mediolateral ground reaction force increased. These pre-to-post changes were significant (p = 0.001–0.033, dz = 0.588–1.060).

Conclusion

The biomechanical effects associated with the cognitive-demand condition were more pronounced following fatigue, with reduced sagittal-plane impact attenuation, faster load rate development, and greater frontal-plane and mediolateral mechanical demands. These findings suggest that badminton training should address cognitive-motor dual-task performance and lower-limb load control under fatigue.

1. Introduction

Badminton involves repeated accelerations, abrupt decelerations, changes of direction, and jump landings, placing substantial eccentric braking and single-leg support demands [1]. The knee is a common site of sports injury, and most anterior cruciate ligament injuries occur without contact during landing or

rapid changes of direction [2,3]. Lunges account for approximately 15% of sport-specific movements and can generate peak impact forces of 2.5 times body weight. They also involve brief braking periods and substantial postural control demands [4,5]. Examining lunge biomechanics can therefore help characterize the mechanical loading associated with badminton movements.

Frontcourt lunges allow badminton players to reach the shuttlecock and decelerate rapidly. Knee flexion, load transfer, and postural adjustments help maintain single-leg stability [6]. Lunge biomechanics vary with movement type, playing level, and experimental conditions [7]. Fatigue and cognitive load affect movement control late in competition [8]. Both local and whole-body fatigue alter cushioning strategies during badminton lunges. Local ankle dorsiflexor fatigue increases the load rate (LR) during backhand lunges by approximately 10.9–13.5 BW/s. Whole-body fatigue reduces peak knee flexion by approximately 4.2° and increases leg stiffness by approximately 16% [9,10]. Greater cognitive demand has also been associated with reduced knee flexion and abduction angles and knee abduction moments, alongside higher ground reaction forces [11]. When movement direction is uncertain, additional demands for stimulus discrimination and response selection increase competition for limited attentional resources [12].

Fatigue and cognitive demands can affect lower-limb motor control, and their combined effects have been examined in landing tasks [13]. Cushioning involves joint motion and external load regulation. Joint range of motion and buffering duration describe the extent and duration of knee flexion, while LR reflects how rapidly external load develops. Assessing these measures together helps relate changes in joint motion to mechanical loading. However, it remains unclear whether findings from landing tasks extend to the badminton backhand forecourt lunge, which requires rapid forward braking and direction selection.

We examined whether the effects of cognitive load on knee cushioning strategies and mechanical load regulation during badminton backhand forecourt lunges depend on fatigue state. We combined a badminton-specific footwork fatigue protocol with a spatial Simon task to compare lunges before and after fatigue, Cognitive load (CL) and without cognitive load (NC). Three-dimensional kinematic and kinetic data were collected synchronously to assess joint motion, moments, and loading characteristics from initial contact to maximum knee flexion. We hypothesized the following: (1) Under CL, cushioning through knee flexion would decrease after fatigue compared with before fatigue. (2) The effects of cognitive load on knee motor control and mechanical loading would vary with fatigue state. (3) Adverse knee biomechanical changes induced by cognitive load under fatigue would increase potential relevance to injury mechanisms.

2. Methods

2.1 Participants

A sensitivity analysis was performed using G*Power 3.1.9.2 (Heinrich Heine University Düsseldorf, Germany) for the primary fatigue × cognitive load interaction [14]. The study used a 2 × 2 fully within-participant design with fatigue state (Pre, Post) and cognitive load (NC, CL) as repeated-measures factors, and their interaction was the primary effect of interest. Because each factor comprised two levels, the interaction could be represented as a within-participant difference of differences and was therefore evaluated using a two-sided paired-samples mean-difference model. With α = 0.05, statistical power (1-β) = 0.80, and a total sample size of 20, the minimum detectable standardized interaction effect was dz = 0.66. Thus, the study was primarily sensitive to moderate-to-large interaction effects.

Eligible participants were male badminton players aged 18–24 years and were classified as Tier 3 athletes (highly trained/national level) according to the participant classification framework proposed [15]. Additional inclusion criteria were right-handed dominance, at least 3 years of systematic badminton training with a minimum of four training sessions per week, and normal or corrected-to-normal vision with the ability to accurately distinguish the color stimuli used in the cognitive task. Participants were excluded if they had sustained a lower-limb musculoskeletal injury within the previous 6 months, participated in high-intensity training or competition within 48 h before testing, or reported lower-limb pain, restricted joint mobility, or other musculoskeletal symptoms that could affect lunge performance. The study was approved by the Institutional Review Board of Jimei University (Approval No. 20260905001). All methods were performed in accordance with relevant guidelines and regulations and the ethical principles of the latest revision of the Declaration of Helsinki. All participants provided written informed consent before participation.

2.2 Experimental design

A 2 × 2 within-participant design crossed fatigue state (pre-fatigue and post-fatigue) with cognitive-load condition (NC and CL). For each participant, Three valid backhand forecourt lunges were averaged per participant per condition. NC/CL order was randomized and counterbalanced at each stage; both Post conditions were completed within 5 min after the fatigue protocol. Before testing, participants practiced the procedures and cognitive-motor dual task and completed at least three familiarization trials to limit learning effects. Starting position, lunge distance, time limit, and trial-validity criteria were standardized across conditions.

The starting position was 1.5 leg lengths from the force plate; leg length was the vertical distance from the anterior superior iliac spine to the ground. Participants faced the screen with their body oriented 45° to the plate's Y-axis [16] **(**Fig. 1**)**. In CL, participants initiated the starting step immediately after stimulus presentation, selected direction by racket color, and lunged at maximal speed, landing centrally on the force plate. The entire movement had to be completed within 3 s. Trials were invalid for (1) reaction time > 2 s; (2) movement direction inconsistent with the visual cue; (3) support-foot placement not fully within the plate's active area or obvious slipping; or (4) obvious loss of balance or movement discontinuity.

2.2.1 Dual-task and fatigue protocols

In the NC condition, participants performed backhand forecourt lunges in a predetermined direction without visual stimuli. The CL condition used a spatial Simon task integrated with badminton footwork [17]. Red, blue, and green rackets cued a leftward backhand lunge, a rightward forehand lunge, and remaining stationary, respectively. Participants responded to racket color while ignoring its screen position. Stimulus color and left/right presentation position were randomized independently, with each color occurring with equal probability. Each stimulus lasted 500 ms, with a stimulus interval of 3 s. Testing continued until three valid red-cue trials were completed. Trials were spatially congruent when stimulus position matched movement direction and incongruent when they were opposite. Green-cue trials were excluded from spatial congruence classification. In CL, participants selected their response after stimulus onset; in NC, movement direction was known in advance. The comparison therefore involved concurrent changes in visual information processing, movement-direction predictability, response selection, and spatial interference processing. Condition effects reflected the combined influence of these task demands.

Sport-specific fatigue was induced using a multidirectional, full-court footwork protocol [18], combining repeated starts, abrupt stops, direction changes, and lunges across front, rear, left, and right court regions. Fatigue criteria were heart rate ≥ 80% of age-predicted maximum (220-age) and rating of perceived exertion (RPE) ≥ 17 on the Borg 6–20 scale [19]. Post testing began immediately after both criteria were met. If heart rate fell below 80% of predicted maximum during testing, participants completed a brief supplementary footwork bout before testing resumed. Heart rate was monitored continuously during the intervention; RPE was recorded before and after the intervention and during Post testing. Supplementary bouts and a 5-min testing window were used to limit recovery during testing.

2.2.2 Backhand lunge

Badminton lunges can be divided into landing, cushioning, and take-off phases based on vertical ground reaction force profiles [20–22] (Fig. 2–4). The landing phase extends from movement preparation to the onset of ground reaction force. The cushioning phase spans initial foot contact to the lowest position of the body's center of mass. The take-off phase comprises push-off until the foot leaves the ground. Cushioning involves impact attenuation, load acceptance, and regulation of knee mechanics. We therefore focused on the weight-acceptance phase, operationally defined as the interval from initial contact to maximum knee flexion.

2.3 Instrumentation

A whole-body rigid-body model was constructed from 41 retroreflective markers positioned according to the Qualisys functional assessment full-body model. Three-dimensional kinematics were recorded using 14 cameras (4 Arqus and 10 Miqus; Qualisys AB, Gothenburg, Sweden). Kinetic data were collected using two floor-embedded three-dimensional force plates (9287CA; Kistler Group, Winterthur, Switzerland). Kinematic and kinetic data were synchronized using Qualisys software.

2.4 Data processing

Data were exported from QTM in C3D format and processed in Visual3D. Knee angles were calculated using Euler angles [23]. Neutral standing was defined as 0°; knee flexion and valgus were positive, and varus was negative. Lateral and vertical ground reaction forces were positive, whereas posterior force was negative. Initial contact was defined as the first instant when vertical ground reaction force exceeded 20 N [24,25]. Maximum knee flexion corresponded to the instant of peak knee flexion.

Kinematic and kinetic data were low-pass filtered using a fourth-order Butterworth filter at 10 and 50 Hz, respectively. Right knee variables[5] were calculated in Visual3D. Kinematic variables included knee flexion and valgus angles, their peak values, sagittal and frontal ranges of motion, and weight-acceptance duration from initial contact to maximum knee flexion. Kinetic variables included peak knee flexion, adduction, and abduction moments. Peak vertical and mediolateral ground reaction forces, peak posterior force along the anteroposterior axis, and LR were also extracted.

Joint moments were normalized to body mass, and ground reaction forces to body weight (BW). When vertical force profiles lacked distinct impact peaks and troughs, the load development phase was identified within the first 30% of stance for LR calculation [26]. Moments, ground reaction forces, and LR were expressed in $N \cdot m \cdot kg^{-1}$, BW, and $BW \cdot s^{-1}$, respectively, LR calculated using the formula:

$$LR = \frac{\mathrm{Peak\ vertical\ GRF}}{\mathrm{Time\ to\ peak\ vertical\ GRF}}$$

2.5 Statistical analysis

Analyses used SPSS 27.0 (IBM Corp., Armonk, NY, USA); data are reported as mean ± standard deviation. Normality was assessed using Shapiro-Wilk tests and residual Q-Q plots,Potential outliers were identified from standardized residuals and condition-specific boxplots and were retained unless attributable to data-entry, measurement, or processing errors. Parametric analyses were used when deviations from residual normality were minor.Two-way repeated-measures ANOVA were conducted with fatigue (Pre, Post) and cognitive load (NC, CL) as within-subject factors. Because both factors had two levels, the sphericity assumption was automatically satisfied. When a significant interaction was identified, four prespecified simple-effect comparisons were performed for each outcome: Pre versus Post within NC, Pre versus Post within CL, NC versus CL at Pre, and NC versus CL at Post. These four comparisons constituted a single correction family for each outcome, and their P values were adjusted using the Benjamini–Hochberg false discovery rate procedure. Accordingly, all reported simple-effect P values are BH-adjusted values. Statistical significance was set at $P < 0.05$. Partial eta squared (η_p^2) values of 0.01, 0.06, and 0.14 and Cohen's *dz* values of 0.20, 0.50, and 0.80 were used as reference thresholds for effect-size interpretation [27].

3. Results

3.1 Participant characteristics

The final analysis included 20 participants (age: 21.2 ± 0.9 years; height: 175.2 ± 2.3 cm; body mass: 64.4 ± 6.2kg; body mass index: 22.2 ± 1.8 kg/m²; badminton training experience: 5.1 ± 0.8 years).Fatigue induction lasted 2.9 ± 0.5 min. At the end of the intervention, Borg RPE was 18.3 ± 1.2 and heart rate was 172.6 ± 8.4 beats/min (86.2% of predicted maximum heart rate).

3.2 Kinematics

Significant fatigue × cognitive load interactions were observed for peak knee flexion angle ($p = 0.007$, $\eta_p^2 = 0.324$), sagittal-plane knee range of motion ($p = 0.013$, $\eta_p^2 = 0.281$), and weight-acceptance duration ($p = 0.017$, $\eta_p^2 = 0.264$). Simple-effects analyses revealed significant pre-to-post differences under the CL condition for peak knee flexion angle ($p = 0.001$, $d = 1.006$, *95% CI*: 0.456–1.539) and sagittal-plane range of motion ($p = 0.013$, $d = 0.681$, 95% CI: 0.185–1.169). Under the NC condition, peak knee flexion angle was significantly lower after fatigue than before fatigue ($p = 0.006$, $d = 0.696$, *95% CI*: 0.198–1.179). At Post, significant differences between the CL and NC conditions were observed for peak knee flexion angle ($p = 0.003$, $d = 0.710$, *95% CI*: 0.210–1.194) and sagittal-plane range of motion ($p = 0.012$, $d = 0.760$, *95% CI*: 0.253–1.252) (Table 1;Figure 2).

Table 1
Knee biomechanics outcomes under the four experimental conditions and interaction effects.

Variable	NC		CL		Interaction		
	Pre	Post	Pre	Post	*F*	*p*	η_p^2
Kinematics							
Flexion at IC (°)	24.57 ± 6.58	22.29 ± 7.11	24.62 ± 6.43	21.63 ± 6.38	0.931	0.347	0.047
Peak flexion angle (°)	83.92 ± 12.61	80.33 ± 13.98	83.55 ± 10.68	76.62 ± 12.13	9.103	**0.007**	0.324
Sagittal-plane ROM (°)	59.35 ± 9.22	58.04 ± 10.45	58.93 ± 8.47	55.00 ± 10.02	7.416	**0.013**	0.281
Valgus at IC (°)	6.15 ± 3.60	6.26 ± 3.56	6.32 ± 3.41	6.38 ± 3.43	0.015	0.904	0.001
Peak valgus (°)	7.63 ± 3.29	7.92 ± 3.39	7.49 ± 3.23	8.40 ± 3.71	1.470	0.240	0.072
Frontal-plane ROM (°)	1.48 ± 1.67	1.67 ± 1.63	1.17 ± 1.47	2.02 ± 2.29	2.006	0.173	0.096
Duration (ms)	534.83 ± 66.30	528.90 ± 79.33	533.83 ± 67.37	493.80 ± 64.06	6.819	**0.017**	0.264
Kinetics							
Peak flexion moment ($N \cdot m \cdot kg^{-1}$)	1.90 ± 0.64	1.74 ± 0.61	1.79 ± 0.66	1.90 ± 0.64	0.149	0.704	0.008
Peak adduction moment ($N \cdot m \cdot kg^{-1}$)	-0.39 ± 0.32	-0.38 ± 0.33	-0.44 ± 0.36	-0.44 ± 0.36	2.172	0.157	0.103
Peak abduction moment ($N \cdot m \cdot kg^{-1}$)	0.69 ± 0.24	0.73 ± 0.21	0.66 ± 0.20	0.80 ± 0.26	5.337	**0.032**	0.219
Peak vGRF (BW)	1.88 ± 0.39	1.83 ± 0.36	1.89 ± 0.39	1.88 ± 0.40	0.260	0.616	0.014
ML-GRF (BW)	0.33 ± 0.08	0.34 ± 0.08	0.33 ± 0.11	0.39 ± 0.10	7.378	**0.014**	0.280
AP-GRF (BW)	-0.79 ± 0.15	-0.80 ± 0.14	-0.79 ± 0.15	-0.81 ± 0.20	0.004	0.945	< 0.001
LR ($BW \cdot s^{-1}$)	44.12 ± 22.55	43.69 ± 18.88	43.60 ± 24.04	50.86 ± 22.59	10.845	**0.004**	0.363

pre: Pre-fatigue stage; post: Post-fatigue stage; NC: No cognitive load; CL:Has cognitive load; IC: Initial contact; ROM: Range of motion; vGRF: Ground reaction force; ML-GRF: Lateral ground reaction force; AP-GRF: Backward ground reaction force; LR: Loading rate.

3.3 Kinecits

Significant fatigue × cognitive load interactions were observed for peak knee abduction moment (p = 0.032,η_p^2 = 0.219), peak mediolateral ground reaction force (p = 0.014, η_p^2 = 0.280), and LR (p = 0.004, η_p^2 = 0.363). Simple-effects analyses showed that, under the CL condition, peak knee abduction moment (p = 0.014, d = 0.749, *95% CI*: 0.243–1.239), LR (p = 0.006, d = 0.760, *95% CI*: 0.253–1.252), and peak mediolateral ground reaction force (p < 0.001, d = 1.060, *95% CI*: 0.499–1.602) were significantly higher after fatigue than before fatigue. At the post-fatigue assessment, LR (p = 0.005, d = 0.855, *95% CI*: 0.332–1.362) and peak mediolateral ground reaction force (p = 0.003, d = 0.841, *95% CI*: 0.320–1.345) were significantly higher under CL than under NC (Table 1; Fig. 3).

To summarize the overall pattern of the fatigue × cognitive load interaction, Fig. 4 presents the biomechanical variables that showed significant interaction effects.

4. Discussion

This study investigated whether the effects of cognitive demands on knee biomechanics during the badminton backhand forecourt lunge differed according to fatigue state. After fatigue, additional decision-making demands were associated with reduced knee flexion and weight-acceptance duration, faster load development, and greater lateral force. These findings partially support the first two hypotheses and provide indirect biomechanical evidence relevant to the potential injury risk proposed in the third.

The dependence of cognitive-load effects on fatigue is consistent with previous cognitive-motor research. Previous studies reported that unanticipated decision-making and additional attentional demands can alter landing posture, knee flexion, and frontal-plane movement under fatigue [28,29]. These findings support a role for perceptual decision-making in lower-limb motor control. This study extends dual-task landing research to the badminton backhand forecourt lunge. Joint excursion, LR, and lateral force were assessed together during weight acceptance. These measures provide complementary information on sport-specific motor control beyond individual joint angles or peak forces. We used a spatial Simon task involving stimulus discrimination, interference suppression, and direction selection to characterize knee mechanical responses to combined decision-making demands and fatigue.

Reduced knee flexion and shorter weight-acceptance duration are consistent with previous badminton fatigue research. Earlier studies reported reduced peak knee flexion and suggested that stance duration may also shorten after fatigue [30]. These findings support fatigue-related adjustments in buffering strategy through changes in joint excursion and movement timing. Although stance duration and the

initial contact to maximum knee flexion interval differ, both findings indicate shorter movement times. Here, peak knee flexion decreased after fatigue even without cognitive load, but reductions in flexion and weight-acceptance duration were more pronounced with added cognitive load. This suggests that direction-selection demands further influence joint excursion and movement timing under fatigue.

The increase in LR is also consistent with previous badminton biomechanics research. Studies using different fatigue protocols reported increased LR during backhand lunges or smash landings [9,31], supporting this measure as an indicator of changes in load development after fatigue. Athletes of different skill levels also show distinct patterns in LR and vertical ground reaction force [32], supporting their use as complementary measures. In this study, the fatigue × cognitive load interaction was significant for LR but was not detected for peak vertical ground reaction force. The frontal-plane results similarly illustrate the complementarity of kinematic and kinetic measures. Peak knee abduction moment increased after fatigue under CL whereas knee valgus angle showed no corresponding interaction. Previous studies found that cognitive challenges can reveal differences in joint moments and power [33]. In some reactive landing tasks, changes in knee flexion and ground reaction force do not necessarily coincide with changes in valgus angle [34]. These findings indicate that joint posture and mechanical loading need not change in parallel. Net joint moments depend on external forces, their moment arms, and segmental motion. Greater frontal-plane mechanical demands therefore need not be accompanied by increased knee valgus.

Variation across studies suggests that the combined effects of fatigue and cognitive load depend on task demands. Previous research detected additional effects of perceptual-cognitive tasks in only some participants [35]. In single-leg landing, fatigue and cognitive constraints may increase peak mediolateral ground reaction force and knee flexion, respectively, without a significant interaction [13]. Cognitive dual-task effects on tibiofemoral kinematics can also vary with the jumping task [34]. The increased knee flexion reported during single-leg landing contrasts with the reduction observed during lunge weight acceptance here. Landing strategies therefore require careful interpretation when applied to badminton lunges involving forward braking and direction selection. Such variation may reflect differences in decision timing, stimulus-response mapping, fatigue protocols, and movement goals.

These results describe changes in biomechanical loading but do not establish an increase in injury risk. Prospective evidence suggests an association between greater knee abduction loading during landing and subsequent anterior cruciate ligament injury [36]. However, biomechanical measures from standardized landing tests cannot be assumed to predict injury in individual athletes [37]. The concurrent changes in knee flexion, weight-acceptance duration, LR, and lateral mechanical demands are therefore best interpreted as altered load regulation under combined fatigue and cognitive load. Prospective follow-up and assessments of internal tissue loading are needed to determine how these patterns relate to knee injury outcomes.Dual-task costs should be interpreted in relation to athletes' physical state and movement demands, rather than assumed to be constant across tasks. Assessment conditions should therefore inform the interpretation of biomechanical outcomes.

This study has several limitations. First, the sample included only young male badminton players, so generalizability across sexes, age groups, and competitive levels remains to be assessed. Second, reaction time and accuracy were not recorded for the spatial Simon task, limiting evaluation of the cognitive load manipulation. Finally, electromyography, internal tissue loading, and prospective injury outcome data were not included in the analysis. The laboratory task also omitted actual incoming shuttlecocks, opponent feints, and consecutive rallies. The findings therefore primarily describe knee biomechanical responses under controlled conditions. Their underlying neuromuscular mechanisms and relationships with actual injury outcomes require further investigation. Future studies should include more diverse participant groups and combine cognitive behavioral measures,musculoskeletal modeling, and prospective follow-up. The findings should also be tested in unanticipated stroke tasks that better reflect competition.

5. Conclusion

In highly trained male badminton players, the effects of cognitive load on knee buffering and load regulation during backhand forecourt lunges depended on fatigue. Under CL, fatigue was associated with reduced sagittal buffering, faster load development, and increased lateral loading and frontal-plane mechanical demands. These changes suggest that sport-specific movement control is shaped by physical state and decision-making demands. Tasks that more closely reflect competitive play, combined with prospective follow-up, are needed to clarify how this biomechanical pattern relates to knee injury outcomes.

Declarations

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Author contributions

Shihua Wang conceived and designed the study, conducted the experiments, processed and analyzed the data, prepared the figures and tables, and drafted the manuscript. Chaofu Chen contributed to the study design and methodology, supervised the experimental procedures and data collection, assisted with the interpretation of the results, and critically revised the manuscript. Zilong Wang and Ziqiang Gan assisted with participant recruitment, experimental procedures, and data collection. Junxian Su contributed to biomechanical data processing and statistical interpretation and critically revised the manuscript. Lei Liu supervised the overall study, provided resources and methodological guidance,

contributed to the interpretation of the findings, and critically revised the manuscript for important intellectual content. All authors reviewed and approved the final manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare no conflicts of interest.

Ethics Approval and Informed Consent

The study was approved by the Institutional Ethics Committee of Jimei University (Approval No. 20260905001). All participants were informed of the study procedures and provided written informed consent before participation.

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Figures

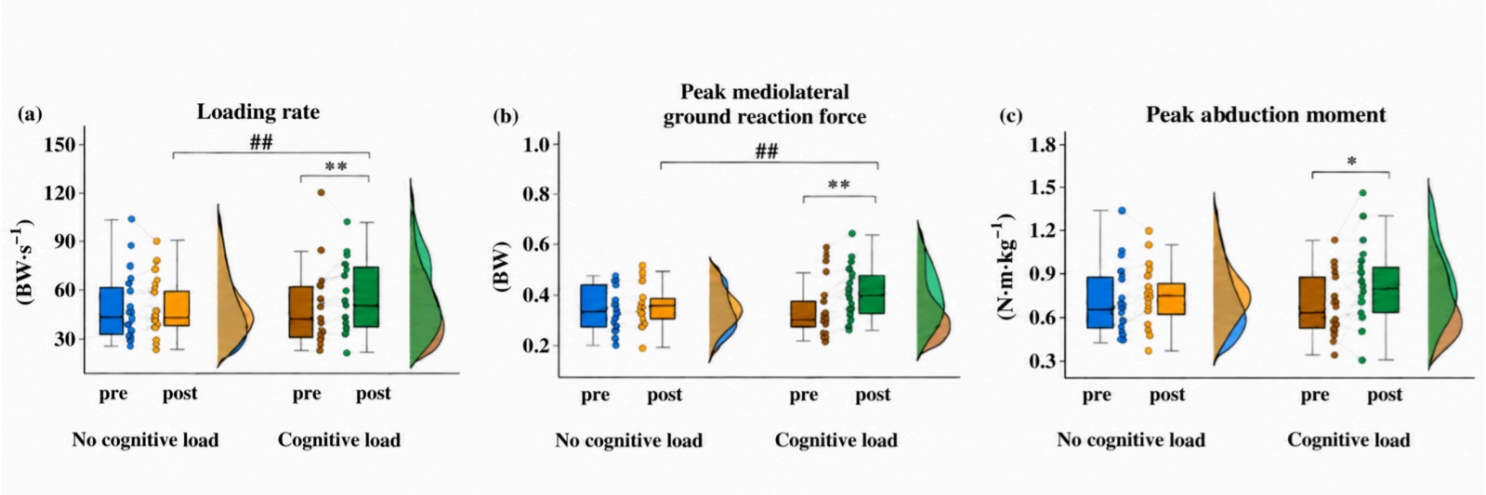


Figure 3

Effects of fatigue and cognitive load on knee abduction moment and ground reaction forces. Raincloud plots show (a) loading rate , (b) peak mediolateral ground reaction force, and (c) peak knee abduction moment. Peak mediolateral ground reaction force is expressed in body weight (BW), loading rate in BW·s^{-1}, and knee abduction moment in N·m·kg^{-1}. Individual observations, boxplots, and half-violin density distributions are shown for pre- and post-fatigue assessments under no cognitive load and cognitive load conditions. Pre and post denote assessments before and after fatigue induction, respectively. Asterisks indicate significant pre-to-post differences within the same cognitive-load condition: $p < 0.05$ and $p < 0.01$. Hash symbols indicate significant differences between the no cognitive load and cognitive load conditions after fatigue: $\#p < 0.05$ and $\#\#p < 0.01$. Benjamini-Hochberg pairwise comparisons were performed following the two-way repeated-measures ANOVA.