ANKLE AND KNEE JOINT FUNCTIONAL INDICES DURING A DROP JUMP: EXPLORING PERFORMANCE RELATIONSHIPS

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The purpose of this study was to describe ankle and knee joint functional indices during a drop jump task and characterize the associations to performance outcomes (jump height, ground contact time, and reactive strength index). Forty-five collegiate or club level athletes performed five drop jumps off a 12-inch box while motion capture and ground reaction force data were recorded. Time-series joint kinematics and kinetics were used to calculate joint functional indices, reported as relative percentages of strut-, spring-, damper-, and motor-like mechanical behavior. Correlation and regression analyses uncovered several significant associations between joint functional indices and performance outcomes. Greater motor-like function at the knee during a drop jump is associated with a greater reactive strength index and jump height as well as a shorter ground contact time.

KEYWORDS: lower extremity, joint kinetics, jump height, ground contact time, reactive strength index.

INTRODUCTION: The importance of the stretch-shortening cycle (SSC) for maximizing impulse and optimizing performance during jumping tasks is well established (Bobbert et al., 1986; Kirby et al., 2011). Practitioners commonly monitor SSC performance in athletes via drop jumps and evaluation of jump height (JH), ground contact time (GCT), and reactive strength index (RSI = JH/GCT) since they are reliable outcomes and easy to interpret (Flanagan & Comyns, 2008; Jarvis et al., 2021; Young, 1995). However, it is challenging to develop a comprehensive understanding of movement strategies that facilitate SSC utilization without detailed biomechanical data. While one study has examined the biomechanical determinants of RSI, focusing on center of mass energetics and vertical stiffness (Kipp et al., 2018), questions remain on how joint-specific biomechanics impact drop jump performance outcomes. Joint-specific mechanics are coordinated to meet movement demands and may also exhibit different functions throughout a movement (Qiao & Jindrich, 2016). For example, a study of joint function during hopping showed that at higher hopping frequencies mechanical behavior of the knee was strut-like (generating a high force over a small range of motion), while the mechanical function of the ankle was spring-like (facilitating the storage and return of elastic energy) (Monte et al., 2021). To describe joint-level biomechanics, the authors applied joint functional indexing (JFI), which uses joint moment, power, and work data during periods of ground contact to characterize mechanical function as strut-, spring-, damper-, and motor-like behavior (Qiao & Jindrich, 2016).

Leveraging JFI to provide detailed joint-level information could improve the efficiency with which performance teams can make decisions and take action as time-series biomechanical data can be reduced to more interpretable relative percentages of the four primary mechanical behaviors. To date, JFI has primarily been used in studies of walking (Kuhman & Hurt, 2019; Qiao & Jindrich, 2016) and hopping (Monte et al., 2021; Qiao, 2021). Describing JFI during drop jumps and relationships to performance may be useful for practitioners looking to better understand how joint-level mechanics impact commonly monitored performance variables like JH, GCT, and RSI during an SSC task. The purpose of this study was to describe ankle and knee JFI during a drop jump task and characterize the associations to performance outcomes (JH, GCT, and RSI).

METHODS: Forty-five NCAA Division I or collegiate club level athletes (Height = 184.5 ± 10.7 cm; Body Mass = 79.5 ± 13.9 kg) volunteered for participation. The sample included 23 males

(11 DI basketball players, 11 club volleyball players, 1 DI track and field jumper) and 22 females (8 DI basketball players, 2 DI volleyball players, 11 club volleyball players, 1 DI track and field jumper). Each athlete provided written informed consent and the study was approved by the local University's IRB. To begin, reflective markers and marker clusters were attached to anatomical landmarks on eight body segments (i.e., torso, pelvis, thighs, shanks, and feet). After a self-selected dynamic warmup, athletes performed five drop jump trials with hands on hips off a 12-inch box. Participants were verbally encouraged to 'jump as high and as fast as they can' with the goal of minimizing GCT while maximizing JH. Athletes were allowed rest as needed. Kinematic data were captured with a 14-camera motion capture system (200 Hz) and kinetic data were collected with bilateral force plates (1000 Hz). Joints in the eight-segment, rigid-body model were allowed six DoF and angles were calculated via inverse kinematics. Inverse dynamics analysis combining force data, kinematics, and anthropometrics was then performed and bilateral data were averaged prior to calculation of positive and negative joint work and, subsequently, joint functional indices (JFI) (Equations 1-4; Qiao and Jindrich, 2016) via custom MATLAB script. Strut-like function is characterized by large moments with little mechanical work due to a small range of motion (Equation 1). Spring-like function involves passive energy storage and return where negative work is followed immediately by positive work (Equation 2). Damper- (Equation 3) and motor-like (Equation 4) function relate to energy dissipation (negative work) and generation (positive work), respectively.

Equation 1*. $Strut\ (\%) = \max\left(1 - \frac{(\mathrm{tTO}-\mathrm{tTD})\int_{\mathrm{tTD}}^{\mathrm{tTO}}|\mathrm{Pjoint}|\mathrm{dt}}{\int_{\mathrm{tTD}}^{\mathrm{tTO}}|\mathrm{Mjoint}|\mathrm{dt}},\ 0\right)\ \mathrm{x}\ 100$

Equation 2*. $Spring\ (\%) = \frac{2 \cdot min\ (|W^{-}flexion|,\ |W^{+}extension|)}{|W^{-}stance| + |W^{+}stance|}\ \mathrm{x}\ (100 - strut)$

Equation 3*. $Damper\ (\%) = \frac{|W^{-}stance| - min\ (|W^{-}flexion|,\ |W^{+}extension|)}{|W^{-}stance| + |W^{+}stance|}\ \mathrm{x}\ (100 - strut)$

Equation 4*. $Motor\ (\%) = \frac{|W^{+}stance| - min\ (|W^{-}flexion|,\ |W^{+}extension|)}{|W^{-}stance| + |W^{+}stance|}\ \mathrm{x}\ (100 - strut)$

*t: time; TO: takeoff; TD: touch down; P: power; M: moment; W: work; stance = touch down to takeoff; flexion = touch down to peak joint flexion; extension = peak joint extension to takeoff

Trial-to-trial reliability of kinematic, kinetic, and performance outcome variables were assessed via coefficients of variation. Pearson's correlations (α = 0.05) were used to investigate the relationships between ankle and knee joint functions (i.e., strut, spring, damper, motor) and drop jump performance outcomes (i.e., JH, GCT, RSI). Backward elimination regression analyses (0.05 threshold for removal) were then performed to describe the linear associations between predictors (ankle and knee JFI) and jump performance outcomes.

RESULTS: Analysis of 217 drop jump trials revealed that trial-to-trial reliability of kinematic and kinetic data, JFI, and jump performance was acceptable (CV% = 5.5 to 16.7). Strut-like behavior was the primary joint function at the ankle and knee (Table 1).

Table 1. Descriptive statistics of jump performance outcomes and joint functional indices.

Variables		*Mean ± Standard Deviation*	*Range*
	Jump Height (m)	0.309 ± 0.077	0.184 – 0.482
	Ground Contact Time (s)	0.380 ± 0.092	0.220 – 0.570
	Reactive Strength Index	0.87 ± 0.33	0.40 – 1.75
Ankle	*Strut (%)*	71.2 ± 15.5	36 – 95
	Spring (%)	21.0 ± 9.1	5 – 39
	Motor (%)	7.8 ± 6.9	0 – 29
	Damper (%)	0.0 ± 0.3	0 – 2
Knee	*Strut (%)*	77.7 ± 13.4	48 – 96
	Spring (%)	16.8 ± 8.2	4 – 33
	Motor (%)	4.5 ± 5.5	0 – 23
	Damper (%)	1.0 ± 1.7	0 – 10

Assessed via intraclass correlation coefficients, reproducibility of the primary JFI (i.e., strut index) at the ankle and knee was excellent (ICC = 0.92) and good (ICC = 0.84), respectively (Koo and Li, 2016). Several significant correlations were uncovered with motor-like function at the knee joint shown to be the only index significantly related to JH (+), GCT (-), and RSI (+). Separate regression analyses also revealed significant associations between predictors and jump performance outcomes (Table 2). One to four JFI predictors accounted for between 32 and 51% of the variation in performance. Spring index (%) was the only predictor of performance at the ankle, and just for JH (+) and GCT (+). Knee motor index (%) was the only JFI parameter at either joint that remained in all three regression equations.

Table 2. Results of backward elimination linear regression analyses of joint functional indices on drop jump performance outcomes

Outcome variable	*Adjusted R^2*	*Predictor(s)*	*Unstandardized B coefficient*	*p*	*95% Confidence Interval of B*
JH	*0.509*	*Ankle Spring*	*0.003*	*0.002*	*0.001 to 0.005*
		Knee Strut	*0.011*	*0.047*	*0.000 to 0.021*
		Knee Spring	*0.013*	*0.026*	*0.002 to 0.024*
		Knee Motor	*0.013*	*0.028*	*0.001 to 0.025*
GCT	*0.325*	*Ankle Spring*	*0.004*	*0.003*	*0.001 to 0.007*
		Knee Motor	*-0.014*	*0.003*	*-0.023 to -0.005*
RSI	*0.339*	*Knee Motor*	*0.035*	*0.001*	*0.021 to 0.050*

**JH: Jump Height; GCT: Ground Contact Time; RSI: Reactive Strength Index*

DISCUSSION: This study is the first to investigate joint functional indices (Qiao & Jindrich, 2016) during a drop jump task. Overarching results indicate that mechanical behavior at the ankle and knee during a jump off a 12-inch box, was predominantly strut-like. A large proportion of strut-like mechanical behavior likely serves to maintain joint stiffness to meet the task demands of maximizing jump height while concurrently minimizing ground contact time (as per instruction). The rank order of JFI after the strut index was spring, motor, and damper. Elastic energy storage and return (spring) was not the primary function despite it being the mechanical behavior most logically associated with an SSC task like the drop jump. Energy generation (motor) was next in rank order and likely relates to the drive to perform positive work during the concentric phase of the jump to maximize the take-off velocity and resulting magnitude of center of mass displacement (i.e., JH). Not surprisingly, based on the task goal, little to no energy dissipation (damper) was observed at either joint.

Regression analyses revealed that JFI accounted for more than 50% of the variation in JH, and more than 32% of the variation in GCT and RSI. First, greater ankle spring and knee strut, spring, and motor function were associated with greater JH. Thus, energy storage and return in both the lower extremity joints helped to maximize jump height. As strut, spring, motor, and damper indices are relative percentages that add to 100%, the similar positive indications of all knee indices except damper in relation to jump height suggests that energy dissipation is detrimental to performance. Next, greater spring function at the ankle was associated with a slightly longer GCT. Taken together with the previous results, it appears that maximizing the storage and return of energy at the ankle, while beneficial for jumping higher, may require spending more time on the ground. Alternatively, greater knee motor function was associated with a shorter time spent on the ground. Thus, generating energy at the knee is beneficial for minimizing GCT in addition to maximizing JH. As the only remaining predictor of RSI, greater knee motor JFI was associated with greater reactive strength performance. Previously, a study that involved measurement of drop jump biomechanics after 15 weeks of power training similarly concluded that knee extension kinetics explained improved performance (Kyröläinen et al., 2005). Our results continue to point to the importance of energy generating behavior at the knee and align with conclusions from a recent hopping study, which suggest that motor-like, rather than spring-like, biomechanics drive maximal effort SSC performance (McBride, 2021).

Interestingly, although strut-like mechanical behavior was the predominant function at both joints, it was only a positive predictor of one outcome (JH) at one joint (knee). Thus, generating high moments over small range of motion, though necessary for maintaining stiffness to meet the task demands (i.e., minimizing GCT and maximize JH), may not be as important when it comes to explaining drop jump performance. In contrast, energy generation at the knee (i.e., motor-like joint function) appears to be the most important mechanical behavior when it comes to peak drop jump performance since it was positively associated with RSI and JH, as well as negatively associated with GCT. Even so, as a preliminary study of JFI in athletes, care should be taken not to overgeneralize the results to different box heights, different task instructions (e.g., maximize JH only), or athletes of different sports or skill levels. Furthermore, while the regression results show practically relevant links to performance in our cohort, associations may differ individually and across time.

CONCLUSION: The primary mechanical behavior for both the knee and ankle during a 12-inch drop jump was strut-like function, which likely helped maintain joint stiffness to meet task demands. Spring-like elastic energy storage and return and motor-like energy generating behavior was also observed, with little to no damper-like energy dissipation. Regression results indicate motor-like knee joint function and the generation of mechanical energy is a key driver of drop jump performance. Specifically, motor-like functional behavior at the knee accounted for more than one-third of the variation in RSI. In addition, motor-like knee joint function also appeared associated with shorter ground contact time and greater jump height. Practitioners looking to evaluate the biomechanics of drop jumps in their athletes may benefit from the use of JFI as detailed time-series kinematics and kinetics can be reduced to more interpretable relative percentages of four mechanical behaviors. Multiple functional indices were strongly associated with drop jump performance with the most important function appearing to be mechanical energy generation (i.e., motor-like functional behavior) at the knee joint.

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