IMPULSE GENERATION AND INITIAL VELOCITY DIFFERENCES IN TWO-FOOT RUNNING JUMPS WITH AND WITHOUT A BASKETBALL

Jun Liu[1], and Antonia Zaferiou[1]

Musculoskeletal Control and Dynamics Lab, Dept. Biomedical Engineering, Stevens Institute of Technology, Hoboken, USA[1]

This study aimed to (1) identify the roles of each leg in impulse generation and (2) determine differences in impulse generation and initial centre of mass velocities in two-foot running jumps with and without a ball. Eight recreational to collegiate basketball players performed three to ten repetitions of two-foot running jumps with and without a ball. We found that the first leg generated more backward and vertical impulse than the second leg in both two-foot running jumps with and without a basketball. Two-foot running jumps with a ball resulted in lower jump height and less vertical impulse generated by the second leg vs. jumps without a ball. These different impulse generation strategies and jump heights when jumping with a ball prompt further research to uncover why there are differences and which training practices can address the differences and lead to higher jump heights with a ball.

KEYWORDS: running jumps, basketball, dunking, two-foot jumps, ground reaction forces, impulse

INTRODUCTION: Jump heights have direct performance implications for basketball (Ziv & Lidor, 2009). However, two-foot running jumps (TFRJs; jumps departing the ground after double support) are poorly understood despite being used in a substantial proportion of jumps during basketball games (Talpey et al., 2021). TFRJs can be performed either with or without a ball in hand in basketball and other sports, like volleyball. This study aimed to first identify the roles of each leg in generating linear impulse during TFRJs with and without a ball and then determine if there are differences in impulses generated and initial centre of mass (COM) velocities between the two tasks.

As TFRJs require redirection of the body’s horizontal momentum vertically, ground reaction force (GRF) impulses applied by each leg present a way to explain momentum control in TFRJs. TFRJs without a ball have been studied in the context of volleyball spike jumps. During these jumps, the first leg generated more vertical and less backward impulse than the second leg, with the distinct roles of each leg emphasized (Fuchs et al., 2019). This study will first examine the roles of each leg in impulse generation in TFRJs with and without a ball before directly comparing the impulse generated by each leg between the two tasks.

The initial COM velocity, as mass-normalized linear momentum, can provide further mechanical context for the impulse generated by each leg. Initial forward velocity was also found to correlate with jump height in volleyball spike jumps (Fuchs et al., 2019; Wagner et al., 2009). As basketball players have been found to run slower when dribbling (Conte et al., 2020), the initial forward velocity may be lower in TFRJs with a ball. Additionally, initial vertical velocity correlated with jump height in two-foot stationary jumps (González-Badillo & Marques, 2010). Therefore, this study will investigate differences in initial forward and vertical velocities and jump heights across TFRJs with and without a ball.

Beyond the demand for dribbling the ball during the run up, basketball players need to control the ball during the take-off. When both hands are on the ball during the jump, arm swing may be limited. As arm swing correlated with jump height in stationary jumps (Lees et al., 2004), limited arm swing is likely to lead to reduction in jump height. This provides additional rationale for our expectation to observe lower jump heights in TFRJs with a ball.

We hypothesize that (1) first leg will generate more vertical and less backward impulse than the second leg in TFRJs with and without a ball. Further, TFRJs with a ball will (2) result in lower jump height and use slower initial forward and vertical velocity and (3) generate significantly less vertical and backward impulse vs. TFRJs without a ball for each leg.

METHODS: Recreational to college-level basketball players (n=8, male, M (SD) of 22.5 (4.9) years of age; 1.80 (0.10) m height; 81.2 (11) kg weight) volunteered for the study in accordance with the IRB. They needed to self-report to be comfortable performing TFRJs with and without a ball and jump at least 0.5 m to be included. They performed self-selected warm up after markers on rigid-body clusters were attached to 15 body segments. Anatomic landmarks were digitized with a probe, allowing COM calculation following de Leva (de Leva, 1996). 3D kinematic (250 fps, Optitrack, OR, USA) and kinetics (1000 Hz, Bertec, OH, USA) were used to capture the movements. Then, they performed TFRJs with and without a ball in randomized order from NBA combine test distance (4.57m). For TFRJs with a ball, they were instructed to jump as high as they can while dribbling the ball during the run up, controlling the ball during the take-off, and dunking the ball into an adjustable hoop with their preferred hand. For TFRJs without a ball, they were instructed to use the same run up and take off, but instead tap their preferred limb on the rim as high as they can. To elicit maximal jump height intent in both tasks, the height of the adjustable hoop was found per-participant during warm up trials(2.7-2.9m). Participants were provided with self-selected rest time in between trials (in addition to transition times between trials of at least 1 minute), and trials deemed unrepresentative by the participant were excluded, resulting in 3-10 successful trials for each participant.

The global axes were defined with forward axis as the average horizontal forward trajectory of the COM during flight, vertical axis as global vertical, and leftward axis as cross product of vertical and forward axes. The outcome variables were all expressed in the global axes. The phase of interest starts from the first leg's ground contact until take-off (**Figure 1**). Jump height is calculated from vertical COM velocity at take-off. Initial horizontal and vertical velocities are the forward and vertical COM velocities, respectively, a frame before initial ground contact. Linear impulse for each leg is the time integral of GRFs of each leg through phase of interest and is normalized by body mass. Net impulse is the sum of impulse from both legs. Signed rank tests were used to compare impulse between legs for hypothesis 1 ($\alpha<0.05$). For hypotheses 2-3, differences between jump heights, initial velocities, and linear impulses across TFRJs with and without a ball were examined with linear mixed models with trial and participant as random effects and jump condition as fixed effect ($\alpha<0.05$).

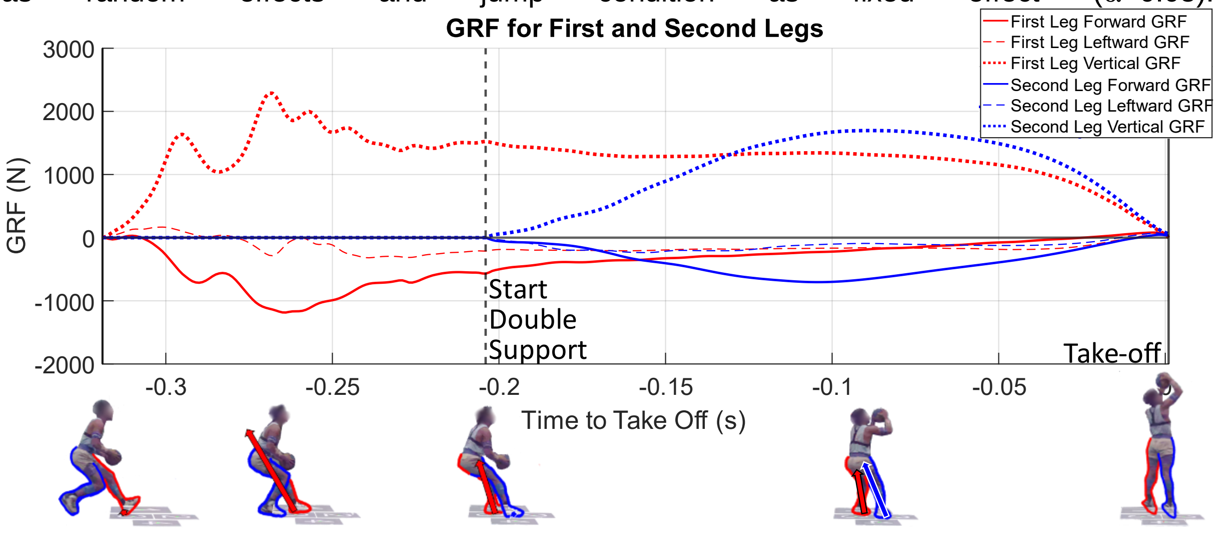

Figure 1: Example ground reaction force (GRF) time series for the first (red) and second (blue) leg in the forward (solid), leftward (dashed), and vertical (dotted) axes in TFRJs with a basketball. Take-off is at 0s, and vertical black line indicate start of double support.

RESULTS: The first leg generated significantly more backward impulse than the second leg in six out of eight participants, the first leg generated significantly more vertical impulse than the second leg in all participants, and these patterns of impulse generation persisted across both TFRJs with and without a ball (**Figure 2**). Jump heights were lower in TFRJs with vs. without a ball (**Table 1**). There was no significant difference in initial forward or vertical velocities (**Table 1**). Of the impulse variables compared in hypothesis 3, the net vertical impulse and second leg vertical impulse were significantly less during TFRJs with vs. without a ball (**Table 1**).

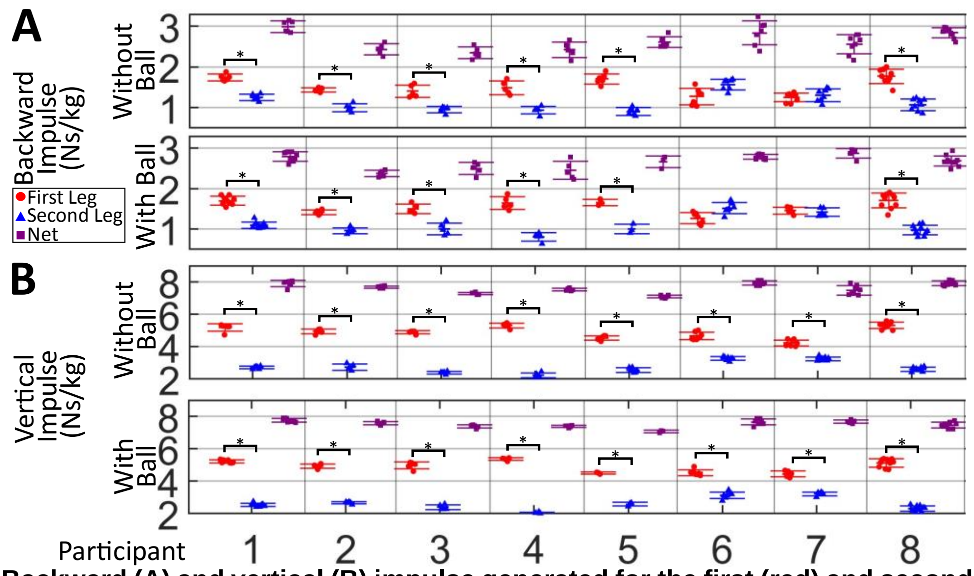

Figure 2: Backward (A) and vertical (B) impulse generated for the first (red) and second (blue) legs for two-foot running jumps for all participants without and with a basketball. Horizontal bars show standard deviation. *p<0.05 with first leg generating more than the second leg.

Table 1: Group estimate marginal means and p-values for the compared variables across two-foot running jumps with and without a ball. Bolded when significant.

Parameter	Estimated Marginal Mean (95% CI)		p-value
	TFRJs without ball	TFRJs with ball	
Jump Height (m)	0.646 (0.589, 0.703)	0.588 (0.531, 0.645)	**<0.0001**
Initial Forward Velocity (m/s)	3.87 (3.74, 4.00)	3.89 (3.76, 4.02)	0.529
Initial Vertical Velocity (m/s)	-0.80 (-0.90, -0.70)	-0.78 (-0.88, -0.68)	0.188
First Leg Forward Impulse (Ns/kg)	-1.51 (-1.66, -1.36)	-1.54 (-1.69, -1.39)	0.347
Second Leg Forward Impulse (Ns/kg)	-1.12 (-1.29 -0.95)	-1.09 (-1.26,-0.91)	0.179
First Leg Vertical Impulse (Ns/kg)	4.89 (4.59, 5.19)	4.88 (4.57, 5.18)	0.714
Second Leg Vertical Impulse (Ns/kg)	2.73 (2.42, 3.03)	2.59 (2.28, 2.90)	**<0.0001**
Net Forward Impulse (Ns/kg)	-2.64 (-2.79, -2.48)	-2.63 (-2.79, -2.47)	0.817
Net Vertical Impulse (Ns/kg)	7.62 (7.41, 7.82)	7.47 (7.26, 7.68)	**0.00011**

DISCUSSION: This study described the roles of each leg in generating linear impulse in TFRJs with and without a ball before investigating the differences in jump heights, initial COM velocities, and impulse generated by each leg between the tasks. Most participants used their first leg to generate more backward impulse and vertical impulse than their second leg. Compared to TFRJs without a ball, jump height, vertical impulse generated by the second leg, and net vertical impulse were lower in TFRJs with a ball.

This study identified the role of each leg in TFRJs performed by basketball players with and without a ball. In both TFRJs with and without a ball, the first leg generated significantly more backward linear impulse in six of eight participants and significantly more vertical impulse in all participants than the second leg. The finding related to backward linear impulse was contrary to what was found in volleyball spike jumps (Fuchs et al., 2019; Wagner et al., 2009), though this could be explained by a few factors. Sports-specific differences between volleyball and basketball may result in different requirements for controlling the body's forward momentum. In this study, the initial forward velocity were also greater than either of the volleyball studies (Fuchs et al., 2019; Wagner et al., 2009), and that require a greater generation of backward

impulse to control the larger forward velocity. Further work with more participants and comparison across sports may help further illustrate and explain this difference.
Although jump heights were lower in TFRJs with vs. without a ball, the non-significant difference in the initial COM velocities may indicate that the run up was not greatly affected in TFRJs with a ball. The significantly lower jump height despite similar initial COM velocities corresponded with significantly less net vertical impulse generation during TFRJs with vs. without a ball. This less net vertical impulse can be due to significantly less vertical impulse generation of the second leg. To understand why these impulses differ, our future studies will compare lower limb coordination and joint kinetics patterns and the influence of arm swing across jumps with and without a ball. This finding also prompts questions about which specific training activities can target the impulse generation capability of second leg in TFRJs with a ball to increase jump height with a ball.
At this time, the sample was limited to only 8 male basketball players, and future work will include female basketball players. The height of the adjustable hoop was selected to elicit high jumping intent and give the players a tangible goal to reach toward, though the height of the hoop is fixed in official games. This study also only investigated whole-body kinematic and kinetic variables, so it is not known how joint-level movement strategies might have differed across the tasks. The statistical approach revealed group-level trends, but further within-participant analysis with enough trials may provide greater insight.

CONCLUSION: This study found that the first leg generated more vertical impulse and typically more backward impulse in TFRJs with and without a basketball, and that jumping with a basketball led to lower jump height and lower second leg and net vertical impulse generation. This difference in impulse generation across the tasks prompts further research into the cause of this difference and which specific training can target this difference. Additionally, the findings differ from those of prior studies of volleyball spikes, which further encourages sport-specific jumping research.

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ACKNOWLEDGEMENTS: We thank participants, Dr. Janine Molino, and research assistants.