CAN A SIMPLIFIED KNEE ABDUCTION MOMENT ESTIMATION BE USED FOR ATHLETE SCREENING? IMPLICATIONS FOR ACL INJURY PREVENTION

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This study aimed to compare a simplified calculation of the knee abduction moment with the traditional inverse dynamics calculation when athletes perform fake-cut maneuvers with different complexities. In the simplified calculation, we multiply the force vector with its lever arm to the knee, projected onto the local coordinate system of the proximal thigh, hence neglecting the inertial contributions from distal segments. We found very strong ranking consistency using Spearman's rank correlation coefficient when using the simplified method compared to the traditional calculation. Independent of the tasks, the simplified method resulted in higher moments than the inverse dynamics. This was caused by ignoring the moment caused by segment linear acceleration generating a counteracting moment by about 7%. An alternative to the complex calculations of inverse dynamics can be used to investigate the contributions of the GRF magnitude and its lever arm to the knee.

KEYWORDS: inverse dynamics, prevention, cutting.

INTRODUCTION: A high number of non-contact anterior cruciate ligament (ACL) injuries occur during cutting manoeuvres (Krosshaug et al. 2007). The external peak knee abduction moment calculated by inverse dynamics (M_{ID}) within the early ground contact phase strongly predicts ACL loading (McLean et al. 2005). However, inverse dynamics requires the calculation of moments transferred by distal segments within the kinematic chain. A simplified knee abduction moment (M_{Simple}) neglecting moments acting on a joint caused by distal segment properties, linear and angular accelerations may provide a fast and reliable estimate of knee joint loading (Kristianslund et al. 2014). However, the influence of the moments caused by segment properties, linear and angular accelerations on the resultant knee abduction moment when performing high-impact movements remains unknown. Therefore, this study aimed to explore: (1) if M_{Simple} which is neglecting the inertia and accelerations of segments within the kinematic chain provides similar joint moment magnitudes as a joint moment calculated by inverse dynamics which takes these factors into account (M_{ID}); (2) the contributions of different moments acting on knee joint in the frontal plane during highly dynamic fake-cut movements; (3) if the rank of the athletes is consistent between M_{Simple} and M_{ID}. (4) To quantify whether the interpretation of intervention changes when using either method subjects performing handball-specific fake-cut manoeuvres with various task complexities were analysed.

METHODS: Fifty-one female (mean ± SD: 66.9 ± 7.8 kg, 1.74 ± 0.06 m, 19.2 ± 3.4 years) handball players volunteered. We captured full-body kinematics with a marker-based tracking system (24 cameras, Qualisys AB, 200 Hz) and ground reaction forces (GRFs) with force plates (AMTI, 1000 Hz) during three standardized fake-cut manoeuvres in a randomized order. For Task 1, athletes were instructed to perform a fake-cut without catching a ball or faking a defender. For Task 2, athletes performed a fake-cut after catching a ball to fake one static defender (Kristianslund et al. 2014). For Task 3, athletes were instructed to approach three dynamic opponents with a fake-cut after catching a ball. Marker trajectories were used to calculate joint kinematics for the foot, knee, and hip joints. Based on joint kinematics and GRF data, M_{ID} was calculated with inverse dynamics (Hof 1992; Willwacher et al. 2016) by using the following equation:

$$M_{ID} = -M_{Free} - [(r_r - r_{lk}) \times F_r]_{Term1} - \sum_{i=1}^{k} [(r_i - r_{lk}) \times m_i g]_{Term2} + \sum_{i=1}^{k} [(r_i - r_{lk}) \times m_i a_i]_{Term3} + \sum_{i=1}^{k} [\frac{d}{d_t}(I_i\, \omega_i)]_{Term4}$$

With M_{Free} being the free moment. Term 1 is the moment caused by the GRF around the knee joint center. The other terms are the moments caused by the weight (Term 2), linear accelerations (Term 3), and angular accelerations (Term 4) of the segments distal to the knee joint within the kinematic chain. The Peak M_{ID} within the first 100 ms after initial contact (vertical GRF threshold > 30N) was computed and normalized to body mass. M_{ID} was expressed in the proximal segment (thigh). Each term of the inverse dynamics equation was also expressed in the thigh segment to allow direct comparison. To quantify the contribution of each term to the M_{ID} (100%), we calculated the percentage share. Repeated-measures ANOVA ($\alpha < .05$) was used to identify differences in the M_{ID} for the three task complexities. Posthoc analysis was performed using Bonferroni corrections ($p_{posthoc}$). Effect size was calculated using partial eta squared (η_p^2). To test whether the interpretation of the task complexity changed when using M_{Simple} (Term 1), we applied an additional repeated-measures ANOVA with posthoc analysis. We calculated Spearman's rank correlation coefficient (r_s) to quantify the ranking consistency when using the M_{ID} and the M_{Simple} for each of the three task complexities.

RESULTS: Term 1, representing M_{Simple}, was the dominant component, regardless of the task complexity, and contributed on average -105 % to the M_{ID} (Table 1). Moments caused by the linear acceleration of the segments (Term 3) accounted for -4 % (Task 3) to -7 % (Task 2) of M_{ID}. The contribution of the free moment on M_{ID} was marginal. The contribution of Term 2 (segment weight) and Term 4 (segment angular acceleration) on M_{ID} were small with 2 % on average and consistent across the three task complexities.

Table 1: Mean and SD of the percentage share [%] of the different moments on the resultant external knee abduction moment from inverse dynamics (M_{ID}). M_{ID} and the simplified knee abduction moment (M_{Simple}) correspond to the moment caused by Term 1. Signs were kept and added up to 100% using the inverse dynamics equation.

	Task 1	Task 2	Task 3	
	Mean ± SD	Mean ± SD	Mean ± SD	
Free moment [%]	0 ± 7	1 ± 6	-1 ± 5	
Term 1 [%]	-105 ± 11	-107 ± 8	-104 ± 8	
Term 2 [%]	2 ± 1	2 ± 1	2 ± 1	
Term 3 [%]	-5 ± 7	-7 ± 6	-4 ± 6	
Term 4 [%]	2 ± 2	3 ± 2	2 ± 2	
M_{ID} [Nm/kg]	1.52 ± 0.54	1.73 ± 0.61	1.64 ± 0.56	p = .02
M_{Simple} [Nm/kg]	1.64 ± 0.61	1.94 ± 0.69	1.76 ± 0.60	p = .02

On average, the simplified moment resulted in 8%, 12%, and 7% greater knee abduction moment magnitudes compared to M_{ID} for Task 1, Task 2, and Task 3, respectively. The repeated-measures ANOVA revealed a statistically significant ($p = .02$, $\eta_p^2 = 0.13$) task effect on the M_{ID} (Table 1, Figure 1). M_{ID} increased significantly ($p_{posthoc} = .002$) from Task 1 (1.52 ± 0.54 Nm/kg) to Task 2 (1.73 ± 0.61 Nm/kg). A further significant ($p_{posthoc} = .02$) increase when comparing Task 1 to Task 3 (1.64 ± 0.56 Nm/kg) could be identified. No statistical difference comparing Task 2 to Task 3 was observed. We found a statistically significant ($p = .02$, $\eta_p^2 = 0.19$) task effect on the M_{Simple} (Table 1, Figure 1). Significantly ($p_{posthoc} < .001$) higher M_{Simple}

were observed for task 2 (1.94 ± 0.69 Nm/kg) compared to task 1 (1.64 ± 0.61 Nm/kg). Simple knee abduction moment in Task 3 (1.76 ± 0.60 Nm/kg) was significantly higher ($p_{posthoc}$ = .039) than Task 1. Comparing Tasks 2 and 3, the M_{Simple} was significantly ($p_{posthoc}$ = .019) higher in Task 2. Regardless of the task complexity, the M_{Simple} resulted in higher moments than M_{ID} regardless of the task complexity.
When comparing the ranking of the M_{ID} and M_{Simple}, we found statistically significant ($p < .001$) correlations with a very strong ($r_s = .96$) relationship for each of the three tasks.

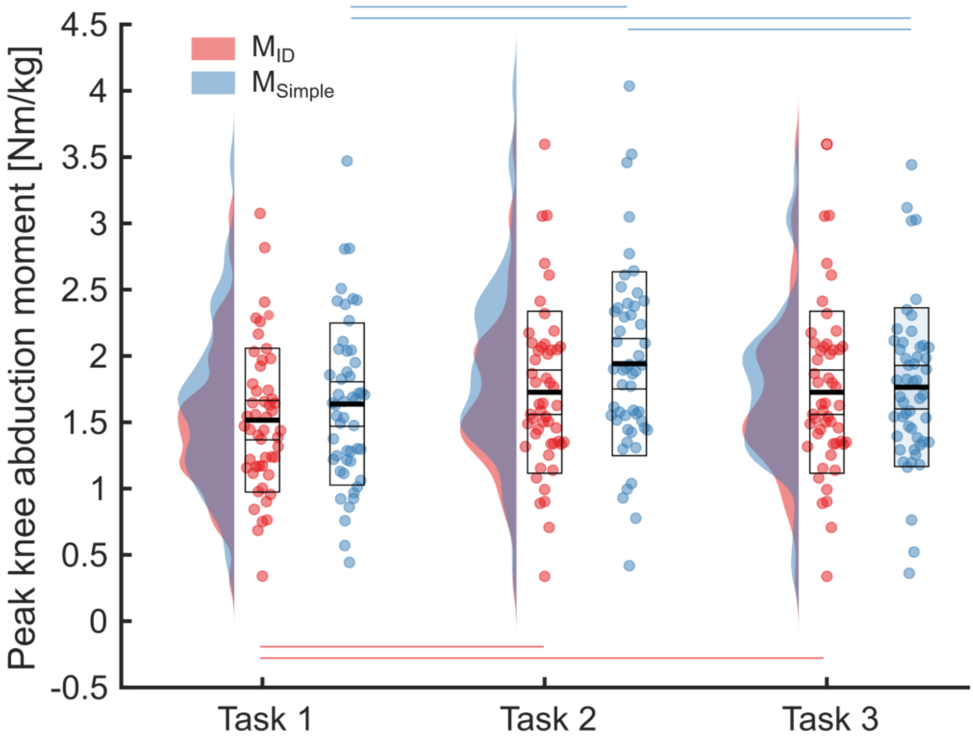

Figure 1: Distribution and box plots for the peak knee abduction moment using inverse dynamics (M_{ID}) and the simplified knee abduction moment (M_{Simple}) within the first 100 ms of stance for the three task complexities. Coloured horizontal lines showing post-hoc results.

DISCUSSION: The purpose of the study was to explore: (1) the contributions of distal segment accelerations and inertia to the frontal plane knee joint moment during highly dynamic fake-cut movements using inverse dynamics calculations (M_{ID}); (2) if a M_{Simple} neglecting the inertia and accelerations of the segments provides similar joint moment magnitudes as calculated by M_{ID}; (3) if the ranking of the athlete's changes when using M_{Simple} and M_{ID}; and (4) to explore if the interpretation of intervention changes when using either method. The peak knee abduction moment calculated by inverse dynamics (M_{ID}) was dominated by the moment caused by the GRF and its lever arm to the knee joint centre. Regardless of the task complexity, the moments caused by the free moment, the weight, and the angular acceleration of the segments within the kinematic chain were negligibly small. The moments caused by the linear acceleration of the segments varied between 5%, 7%, and 4% for Task 1, 2, and 3, respectively. As a result of neglecting the counteracting moment generated by linear segment accelerations, the simplified knee abduction moment slightly overestimates the moment computed by inverse dynamics. However, these overestimations tend to be systematic, as indicated by the very high ranking consistency of the two approaches compared. Moreover, the ranking consistency was very strong and independent of the cutting task performed. Since M_{Simple} was systematically higher than M_{ID} across all tasks and the rankings were consistent, the interpretations of the results are comparable. Despite overestimating the resultant external moments, using a simplified moment yields clear benefits. For example, this approach is ideal for investigating the relative contributions of the GRF and its lever arm to the external joint moments. Using the conventional approach of filtering marker position data and then differentiating in the time domain can lead to erroneous higher derivatives due to noise amplification (Mai and Willwacher

2019). The magnitudes of the simplified knee abduction moment we used agreed with other simplification approaches. For example, Kristianslund and colleagues (2014) found an average simplified knee abduction moment of 1.64 Nm/kg while athletes performed a fake-cut manoeuvre comparable to Task 2 in our study. Potentially, using a simplified knee abduction moment encourages researchers to report the lever arm, GRFs, and the resulting knee abduction moment separately. A component-wise analysis, i.e., decomposing a joint moment into its lever arm and the force acting on the joint, can help understand the causative factors of injuries. However, attention should be paid to the approach used when comparing to critical threshold values for knee joint loading from the literature.

CONCLUSION: In conclusion, a simplified knee abduction moment can be used for athlete screening. However, caution needs to be paid when setting or comparing to critical threshold values derived from studies using other approaches. When performing highly dynamic movement tasks, a simplified knee abduction moment can systematically overestimate the knee abduction moments calculated by inverse dynamics, on average by 9%. We hope that this paper encourages researchers to develop time- and cost-efficient screening tools and biofeedback systems.

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