JOINT KINEMATIC VARIABILITY IN THE AERIAL AND LANDING PHASES OF BACKWARD ROTATING DISMOUNTS FROM BEAM

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This study aimed to develop insight into the joint kinematic variability in backward rotating dismounts from beam. Two-dimensional lower-body coordinate data were obtained for ten backward piked (BP) and tucked (BT) dismounts performed by four gymnasts (N = 80 trials). The within-gymnast coefficient of variation (CV%) in the joint angle profiles was lower in the aerial-landing phase transition than the remaining dismount element. The CV% was consistently larger in the initial joint configurations of the BP aerial and landing phases than the more basic BT skill. Initial ankle and hip joint landing configurations produced the largest CV% difference between skills (ankle: 9.4 %, hip: 9.4 %). The development of complex dismounts from beam requires a pre-programmed control strategy allowing joint kinematic modulations at the onset of aerial and landing phases.

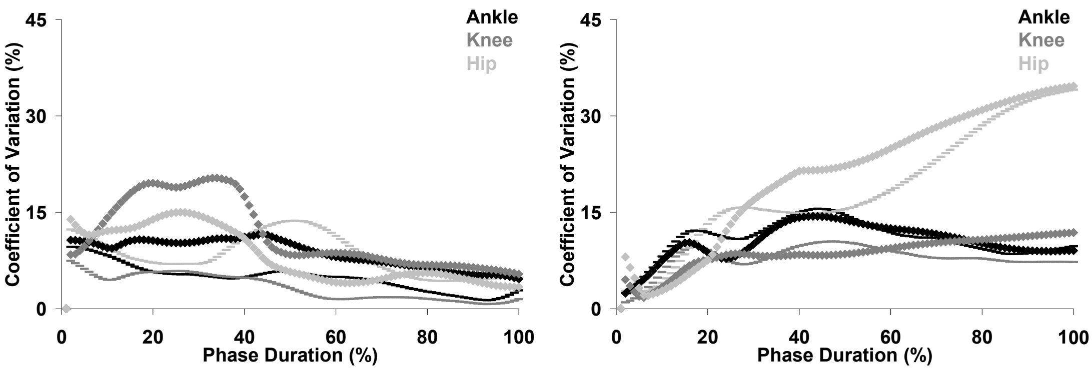
KEY WORDS: gymnastics, tucked, piked, coefficient of variation, skill development

INTRODUCTION: Dismounting is a crucial element in gymnastic routines and the mastering of fundamental dismounts has been considered beneficial in providing a foundation for the development of more complex skills (Takei *et al*., 1992). While the dismount element is commonly defined by an aerial and landing phase, diverse spatial orientation objectives in the aerial phase leads to a distinction in skill complexity. In dismounting from the beam apparatus, the backward tucked (BT) somersault can be considered a basic skill for competitive level gymnasts to master, while the development of a more complex dismount involves the acquisition of the back piked (BP) version. As dismount skill complexity increases, modified task objectives must be addressed by the gymnast's biological structures and varied movement patterns are potentially required to achieve effective skill development.
Variability in human movement has traditionally been considered detrimental, and van Emmerik *et al.* (2005) highlighted that the majority of studies on motor learning have linked a decreased task performance variation with the learning process. In contrast, contemporary research employing a dynamical systems perspective has considered variability to have a functional role in locomotion and athletic tasks (Hamill *et al.,* 1999; van Emmerik et al., 2005). Changes to the multi-joint movement strategy executed to achieve a desired performance outcome were recently considered necessary by Bradshaw *et al. (*2007) to accommodate the demands of a sprint-based athletic task. Skill development in triple-jump has similarly been associated with the presence of a more variable inter-limb coordination strategy (Wilson *et al.*, 2008).
While insight into the movement variability in gymnastic skill development has been limited, Irwin & Kerwin (2007) recently advocated the importance of considering movement variability in understanding skill development due to discrepancies in joint kinematic variability in longswing progressions. Examination of the kinematic variability associated with dismounting has the potential to enhance insight into the control strategy modulation demanded for effective skill development in a commonly performed gymnastic task, and to further contribute to understanding of the role of movement variability in performance development. While between-gymnast comparisons have traditionally been employed to examine the characteristics of complex skills in gymnastics, Gervais & Dunn (2003) advocated the use of within-gymnast analyses for gaining insight into training and control strategies used in learning fundamental gymnastics dismounts. The aim of this study was to develop insight into the within-gymnast joint kinematic variability associated with the skill development of backward rotating dismounts from beam. Increased kinematic variability was hypothesised to be greater in the landing than aerial phase, and with the execution of a more complex skill.

METHODS: Four national level female gymnasts (mean ± SD height: 1.64 ±0.08 m, body mass: 59.0 ±6.9 kg) were recruited for the study and gave written informed consent. The experimental protocols were approved by the University's Research Ethics Committee. During the collection session, each gymnast performed ten successful backward rotating somersault dismounts from beam in piked and tucked positions (N = 20 trials for each gymnast). Successful performances were qualitatively judged by a national-level coach using the FIG Code of Points (2008). During the data collection session, active markers were located on the lateral, right side of each gymnast at the metatarsalphalangeal (mtp) and on the ankle, knee, hip and shoulder joint centres. Co-aligned CODA CX1 motion analysis scanners (Charnwood Dynamics Ltd., Leicestershire, UK) were used to obtain the active marker locations (sample rate: 200 Hz; sample duration: 6 s) during each dismount routine.

The three-dimensional marker coordinate data were subsequently reduced to two-dimensions (z-vertical and y-anterior-posterior) and low-passed filtered at 10 Hz. Separate aerial and landing phases were defined for each dismount routine. The aerial phase was defined as the duration between the instant at which the mtp z-displacement first exceeded the respective loaded displacement on the beam, and the time point prior to the instant at which the vertical displacement of the mtp marker descended below the unloaded landing surface height (ground contact). The landing phase was subsequently defined as the duration between first ground contact, and the instant at which the mtp joint maintained a stable, loaded position on the ground.
Sagittal plane ankle, knee and hip joint kinematic profiles were determined for the dismount duration using the filtered two-dimensional coordinate data and the phase-specific initial, range of motion (ROM), peak flexion and flexion angular velocity of each joint were identified. The within-gymnast coefficient of variation (CV%) in the lower-body kinematic measures were calculated as the percentage of the mean standard deviation across gymnasts (N = 4 gymnasts) relative to the group mean for the respective discrete kinematic measure. Joint angle CV% profiles were determined as the within-gymnast CV% at each time point in the respective aerial and landing phase. Paired t-tests (α level: 0.05) were conducted to examine between phase differences in the discrete measures CV% for the combined dismount routines.

RESULTS: Within-gymnast variability in the joint kinematic profiles (Figure 1) was typically lower at the completion of the aerial phase and the subsequent onset of landing compared to the remainder of the respective phases. Individual joint analyses demonstrated the hip joint angle CV% profile to be notably more prominent than the ankle and knee joint profiles in the latter stages of the landing phase.



a. b.

Figure 1: Within-gymnast CV% in joint angle profiles in the aerial (a) and landing (b) phase of BP (thin) and BT (thick) dismounts.

As illustrated in Table 1, the within-gymnast CV% was consistently larger for the initial joint configurations used in the aerial and landing phases of the BP dismount compared to the corresponding phases of the more basic BT skill. The ankle and hip joint configuration used at the onset of landing produced the largest CV% difference between skills (ankle: 9.4%, hip: 9.4%). In contrast, the BT skill was associated with a greater CV% in the knee and hip joint kinematic landing strategies than used in the more complex BP skill. Between skills CV% differences were greatest for the aerial phase hip joint ROM (22.9%) and the peak knee angular velocity (35.6%) of the landing phase.

Table 1 Within-gymnast CV% in lower-body kinematics of the aerial and landing phases of BP and BT dismount routines

	Aerial	Landing	Aerial	Landing	Aerial	Landing
	Initial Ankle θ (%)*		**Initial Knee θ (%)***		**Initial Hip θ (%)***	
BP	9.6	11.5	7.5	7.8	12.4	13.6
BT	2.4	2.1	1.6	2.1	3.6	4.2
	ROM Ankle θ (%)		**ROM Knee θ (%)**		**ROM Hip θ (%)***	
BP	12.4	13.3	12.2	6.0	3.7	9.1
BT	11.9	10.5	9.9	13.8	26.6	24.9
	Maximum Flexion (%)*		**Maximum Flexion (%)**		**Maximum Flexion (%)***	
BP	5.2	8.5	5.9	7.1	5.6	4.7
BT	4.8	4.4	6.6	10.8	11.5	15.7
	Peak Ankle ω (%)		**Peak Knee ω (%)**		**Peak Hip ω (%)***	
BP	11.8	10.1	17.0	6.1	6.0	6.3
BT	9.8	9.0	4.9	42.6	12.2	22.6

*Significant difference between aerial and landing phase CV% at $p<0.05$ (N = 8 phases x 8 phases)

DISCUSSION: The within-gymnast kinematic variability associated with the execution of the aerial and landing phases of a basic and more complex backward rotating dismount from beam was examined. More invariant lower-body kinematic measures were typically associated with the aerial compared to the subsequent landing phase, which suggested that the gymnasts were more readily capable of replicating the movement patterns required to satisfy the task constraints of the flight routine. The dismount routines were commonly characterised by a relatively invariant joint kinematic profile at the end and onset of the aerial and landing phases respectively, when compared to the remaining dismount profile. The invariant lower-body kinematic profiles in the transfer from flight to ground contact suggested the need for a more constrained control strategy during the phase transition, which contradicted the dynamical systems perspective suggesting movement pattern variability has a functional role in allowing transitions between movement patterns (van Emmerik *et al.*, 2005). The individual joint analyses conducted in this investigation may explain the discrepancy in findings from previous applications of the dynamical systems theory, which have frequently examined joint coupling control strategies. Future investigation of the coordination pattern variability in the joint strategy used may subsequently be suggested to extend insight into the phase-based demands of dismounting skills.

Increasing skill complexity was associated with greater within-gymnast modulations in the initial ankle, knee and hip joint angle configurations used in the BP and BT phase strategies, and was consistently associated with reduced variability in the landing phase knee and hip joint kinematics. In contrast, the landing phase variability in the discrete ankle joint measures was marginally larger in the BP skill compared to the more basic BT skill. The larger within-gymnast variability in the initial joint configurations used in the BP skill suggested that the execution of more complex dismount skills requires a control strategy that allows greater flexibility in the joint kinematic patterns used in initiating the aerial and landing phases. In contrast, the progression from a basic to more complex dismount skill may be considered to require a more constrained knee and hip joint control strategy during landing as evidenced by the more consistent BP knee and hip kinematic measures. The relatively invariant knee and hip joint and less consistent ankle joint kinematic measures associated with the complex BP landing strategy further supported previous suggestions (Irwin & Kerwin, 2005) that kinematic modifications in gymnastic skill development are specific to individual joints. Examination of the performance variability associated with increasing task complexity may be beneficial in furthering understanding of the control strategies used in successful dismount performances and may support the previously suggested (van Emmerik *et al*., 2005) departure from traditional concepts that equate variability with inferior performance.

CONCLUSION: Backward rotating piked and tucked dismounts from beam are commonly defined by a flight-ground contact transition characterised by a constrained lower-body joint kinematic pattern. The development of more complex dismount routines from beam however, requires the use of a pre-programmed movement pattern that allows perturbations in the initial configurations of the lower-body joints at the onset of the aerial and landing phases. The effective development of more complex gymnastic dismounts is further characterised by independent modulations to individual lower-body joint patterns within the separate dismount phases.

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