JOINT- AND LOAD-SPECIFIC ASYMMETRIES DURING THREE LOWER EXTREMITY RESISTANCE TRAINING EXERCISES

Michael H. Haischer[1,2], Nayun Ahn[1], Hoon Kim[3], Emily Jacobson[4], and Kristof Kipp[1]

Department of Physical Therapy, Marquette University, Milwaukee, WI, USA[1]
Athletic and Human Performance Research Center, Marquette University, Milwaukee, WI, USA[2]
Joint Department of Biomedical Engineering, University of North Carolina at Chapel Hill and North Carolina State University, Chapel Hill, NC, USA[3]
Department of Intercollegiate Athletics, Marquette University, Milwaukee, WI, USA[4]

The purpose of this study was characterize the consistency of limb symmetries at the knee and hip in the front squat, hexagonal barbell deadlift, and Romanian deadlift across three loads (40%, 60%, 80% of front squat one-repetition maximum). Eight female collegiate soccer players performed three repetitions at each aforementioned load and for each exercise while motion capture and ground reaction force data were recorded. Bilateral net joint moments were calculated and used to quantify joint-specific limb symmetry indices (LSI) for each exercise and loading condition. Correlation analyses revealed similarity in LSI at the knee and hip within all exercises and between the front squat and hexagonal barbell deadlift. At the joint level, greater biomechanical similarity between tasks seems to result in greater consistency of interlimb asymmetries.

KEYWORDS: squat, deadlift, net joint moment.

INTRODUCTION: Interlimb asymmetries, defined as unequal performance or output between limbs (Bishop et al., 2018; Keeley et al., 2011), are often researched as they have been tenuously associated with sports performance and injury risk factors (Bishop et al., 2017). While some level of asymmetry may be normal in elite performers (Maloney et al., 2019), thresholds have been proposed to inform return to play and identify risk of injury (Bishop et al., 2017). Thus, practitioners may try to ameliorate asymmetries through the design of resistance training programs with the goal of reducing risk of injury and improving performance. However, biomechanical asymmetry values within individuals can change with task demands (Flanagan & Salem, 2007; Kobayashi et al., 2010). Knowing how consistent asymmetries are with changes in training stimuli, such as choosing a different exercise or load, would be valuable for optimizing resistance training programs. For example, if varying loads within a bilateral exercise does not alter between-limb differences in mechanical effort, the ability of that exercise to reduce potentially harmful asymmetries over time with training may be limited.

Three common lower-body resistance training exercises are the front squat (FS), hexagonal barbell deadlift (HEX), and Romanian deadlift (RDL). Although each of these exercises are frequently used to develop strength and power (Bird & Barrington-Higgs, 2010; Bird & Casey, 2012; Lockie & Lazar, 2017), it is unclear how consistent the asymmetries of lower extremity net joint moments (NJMs) are across these tasks and under different loading conditions. The generalized motor program theory (Schmidt, 1975) would suggest that NJM magnitudes should scale proportionally with load, resulting in corresponding asymmetries that remain largely consistent, as each loading condition is a slight variation on constraints within the same skill. In agreement with this hypothesis, previous work examined bilateral asymmetries during the back squat and demonstrated that changes in load did not impact bilateral differences in average net joint moments (Flanagan & Salem, 2007). On the other hand, more recent work showed that asymmetry of peak NJM may be impacted by resistance training load (Kobayashi et al., 2010). Notably, this change in asymmetry of NJM was observed without changes to asymmetry of GRF. Thus, evaluating joint-specific asymmetries

may be a better approach than studying GRF when looking to gain insights into between-limb differences.
The purpose of this study was to characterize the consistency of asymmetries of NJM at the knee and hip in the front squat, hexagonal barbell deadlift, and Romanian deadlift across three loads (40%, 60%, 80% of front squat one-repetition maximum) via correlation analysis. Practitioners may benefit from knowledge about the similarity of joint-specific asymmetries during common exercises and at different loads when devising training programs for athletes.

METHODS: Eight NCAA Division I female soccer players (Height = 177.2 ± 3.0 cm; Body Mass = 66.8 ± 7.1 kg) volunteered for participation in this study. Each player provided written informed consent and the study was approved by the local University's IRB. Data collection occurred during an offseason training period, in which all players participated in a resistance training program that included all exercises within the data collection session. Thus, players had familiarity with the exercises and loads used during the study.
Upon arriving at the lab, reflective markers were attached to anatomical landmarks and marker clusters were attached to the pelvis, thigh, shank, and foot. Players then performed a standardized dynamic warm-up consisting of basic callisthenic exercises. Exercise testing involved the FS, HEX, and RDL, with only the latter two exercises performed in random order. Front squat was always evaluated first as the reference exercise used to inform testing loads; one-repetition maximum (1RM) was tested at an earlier timepoint under supervision of the player's strength and conditioning coach. Within each exercise, participants performed a warm-up set with the bar before performing three repetitions of each exercise with 40%, 60%, and 80% of their FS 1RM. All loads were progressively increased. Rest periods between loads and exercises lasted at least one minute.
Kinematic data were captured at 100Hz with a 14-camera motion capture system, while kinetic data were collected with two force plates at 1000Hz. To calculate the NJM at the knee and hip joints, inverse dynamics analysis combining GRF, kinematics, and anthropometrics were performed. Positive and negative moments corresponded to extension and flexion, respectively. Peak NJM at the two joints were extracted during each trial at each load and for each exercise, and then averaged across trials within each player. Limb symmetry indices (LSI) for the peak NJM were then calculated based on the equation provided by Bell and colleagues (2014), where zero indicates symmetry between limbs, and positive and negative values indicate greater right and left limb values, respectively. Trial-to-trial reliability of NJM was assessed via coefficients of variation. Pearson correlational analysis with 1000 replicate sample bootstrapping was used to investigate the relationships between joint-specific LSI obtained from each task and loading condition. Results were interpreted as trivial < 0.1, weak = 0.1-0.3, moderate = 0.3-0.5, strong = 0.5-0.7, very strong = 0.7-0.9, and nearly perfect > 0.9 (Raya-González et al., 2021), with statistical significance set to $\alpha = 0.05$.

RESULTS: Trial-to-trial CV indicated that reliability of bilateral NJM were good (10 to 20%) to excellent (≤ 10%) except for the knee during the 40%1RM RDL. Reliability in this condition was poor (≥ 30%), but may be explained by small NJM since the degree of agreement partially depends on the magnitude of the measured value (Atkinson & Nevill, 1998). Compared to FS and HEX, the execution of the RDL requires relatively less knee NJM. The large variability in LSI data across individuals is reflected in the large standard deviation (SD) values (Table 1).
LSI at the knee joint were generally consistent in that very strong to nearly perfect positive correlations were revealed between all loading conditions of FS and HEX (Table 2). Similarly, RDL loading conditions exhibited very strong and nearly perfect positive correlations with one another. On the other hand, very strong negative correlations were found between knee joint LSI derived from RDL and those obtained from FS and HEX. Overall, the relationships at the hip joint were akin those at the knee joint, with positive correlations between FS and HEX, and within all exercises. However, unlike the knee, analysis of hip joint data did not uncover negative correlations between RDL and the two other exercises.

Table 1: Mean ± standard deviation limb symmetry indices across joint, task, and load.

		Limb Symmetry Index		
Joint	Exercise	40%1RM	60%1RM	80%1RM
Knee	FS	9.8 ± 16.0	9.4 ± 16.6	7.5 ± 12.3
	HEX	6.3 ± 18.5	10.0 ± 14.2	7.4 ± 13.0
	RDL	2.5 ± 40.6	-5.8 ± 43.6	-5.0 ± 36.3
Hip	FS	4.4 ± 13.0	1.0 ± 12.1	6.8 ± 15.1
	HEX	4.8 ± 15.5	6.8 ± 19.6	2.0 ± 12.8
	RDL	9.6 ± 14.4	3.6 ± 8.5	3.9 ± 9.8

1RM: One-Repetition Maximum; FS: Front Squat; HEX: Hexagonal Barbell Deadlift; RDL: Romanian Deadlift

Table 2: Correlation matrix of limb symmetry indices within the knee and hip joints by task and load.

Task		FS			HEX			RDL		
Load (%1RM)		40	60	80	40	60	80	40	60	80
		Hip								
FS40			.795*	.719*	.861	.919	.753	.143	-.159	-.239
FS60		.947^		.852**	.840**	.752*	.805*	.017	-.245	-.206
FS80		.873**	.868**		.729*	.816*	.728*	.064	-.199	-.039
HEX40	**Knee**	.928^	.906**	.899**		.853**	.903**	.420	.138	.119
HEX60		.916^	.857**	.948^	.889**		.873	.335	-.018	.006
HEX80		.874**	.876**	.982^	.907**	.962^		.507	.171	.206
RDL40		-.439	-.634	-.586	-.471	-.570	-.655		.895**	.853**
RDL60		-.575	-.762*	-.673	-.633	-.650	-.756*	.943^		.815*
RDL80		-.512	-.724*	-.712*	-.560	-.603	-.739*	.892**	.931^	

1RM: One-Repetition Maximum; FS: Front Squat; HEX: Hexagonal Barbell Deadlift; RDL: Romanian Deadlift

*p < 0.05; **p ≤ 0.01; ^p ≤ 0.001; all indicate 95% confidence intervals do not include zero

DISCUSSION: This study was aimed at evaluating the strength of the relationships between joint-specific symmetry of the knee and hip in the front squat, hexagonal barbell deadlift, and Romanian deadlift across three loads (40%, 60%, 80% of front squat 1RM). In agreement with the generalized motor program theory (Schmidt, 1975), the results showed LSI to be largely consistent at the knee and hip, with very strong to nearly perfect positive correlations between similarly skilled exercises (i.e., FS and HEX) and loading conditions within a single exercise (Table 2). Further, at the knee joint, asymmetries during FS and HEX are negatively associated those seen during RDL. From a practical standpoint, this suggests that the knee that experiences greater demands is opposite between RDL and the two other exercises.

Taken together, the results of this study suggest that the consistency of asymmetries at the joint level is strongly related to biomechanical similarity between tasks. Though HEX is considered a deadlift variation, it is arguably a push-dominant exercise that more closely resembles the squat. While the positioning of the external load is different between FS and HEX, the knee and hip kinematics of those exercises are notably similar (e.g., range-of-motion: ROM). Alternatively, the biomechanics of the RDL are dissimilar to the other two exercises, with a smaller ROM and NJM at the knee dictating greater hip NJM when executing the movement. RDL involves pulling the load from the ground, as opposed to pushing, and the opposing nature of the exercises provides a possible explanation for the strong negative correlations observed between asymmetries during RDL and those from FS and HEX.

To date, there is a paucity of data on asymmetry of lower extremity biomechanics across a range of resistance training exercises and loads. Our study helps to fill this gap in the

literature by directly examining correlations between joint-specific lower limb symmetries across common exercise variations and loading conditions. Based on our results, adjusting the load within a bilateral task or choosing a biomechanically similar bilateral exercise does not appreciably change between-limb differences in the mechanical effort required to complete the movement. Thus, bilateral exercises may be limited in their ability to reduce asymmetries within a resistance training program, as mechanical effort cannot be substantially shifted to preferentially target one limb or the other. Sport scientists would benefit from examining whether the relationship between joint-specific asymmetries within and across biomechanically similar exercises improves with strength and skill (e.g., training age), as this would seem to suggest improved coordination and control within a general motor program even if the magnitude of interlimb asymmetry is not reduced. Additionally, future work should investigate whether these relationships diminish at loads close to 1RM, as joints within one limb may be operating closer to maximum capacity, requiring the contralateral joint to disproportionately accommodate the increased demand.

CONCLUSION: This study correlated symmetry of lower extremity NJM across the same loads (40%, 60%, 80% of front squat 1RM) in the front squat, hexagonal barbell deadlift, and Romanian deadlift. Overarching results indicate very strong correlations at the knee and hip between loading conditions within each exercise, and between FS and HEX. Asymmetries during RDL did not correlate as well with FS and HEX, especially under lighter loads. Greater biomechanical similarity between exercises seems to result in greater consistency of joint-specific asymmetries, as differing loads within a single exercise does not substantially alter asymmetries. The consistency of asymmetries shown during variations of bilateral tasks highlights the potential limitations of these exercises when attempting to reduce between-limb differences.

REFERENCES

Atkinson, G. & Nevill, A.M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, 26(4), 217-238.

Bell, D.R., Sanfilippo, J.L, Binkley, N., & Heiderscheit, B.C. (2014). Lean mass symmetry influences force and power asymmetry during jumping in collegiate athletes. *Journal of Strength and Conditioning Research*, 28(4), 884-891.

Bird, S. & Barrington-Higgs, B. (2010). Exploring the deadlift. *Strength and Conditioning Journal*, 32(2), 46-51.

Bird, S. & Casey, S. (2012). Exploring the front squat. *Strength and Conditioning Journal*, 34(2), 27-33.

Bishop, C., Read, P., Lake, J., Chavda, S., & Turner, A. (2018). Inter-limb asymmetries: understanding how to calculate differences from bilateral and unilateral tests. *Strength and Conditioning Journal*, 40, 1-6.

Bishop, C., Turner, A., & Read, P. (2017). Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *Journal of Sports Sciences*, 36(10), 1135-1144.

Flanagan, S.P. & Salem, G.J. (2007). Bilateral differences in the net joint torques during the squat exercise. *Journal of Strength and Conditioning Research*, 21(4), 1220-1226.

Keeley, D.W., Plummer, H.A., & Oliver, G.D. (2011). Predicting asymmetrical lower extremity strength deficits in college aged men and women using common horizontal and vertical power field tests: a possible screening mechanism. *Journal of Strength and Conditioning Research*, 25(6): 1632-1637.

Kobayashi, Y., Kubo, J., Matsuo, A., Matsubayashi, T., Kobayashi, K., & Ishii, N. (2010). Bilateral asymmetry in joint torque during squat exercise performed by long jumpers. *Journal of Strength and Conditioning Research*, 24(10), 2826-2830.

Lockie, R. & Lazar, A. (2017). Exercise technique: applying the hexagonal bar to strength and power training. *Strength and Conditioning Journal*, 39(5), 24-32.

Maloney, S.J. The relationship between asymmetry and athletic performance: a critical review. *Journal of Strength and Conditioning Research*, 33(9), 2579-2593.

Raya-González, J., Clemente, F.M., & Castillo, D. (2021). Analyzing the magnitude of interlimb asymmetries in young female soccer players: A preliminary study. *International Journal of Environmental Research and Public Health*, 18, 475.

Schmidt, R.A. (1975). Schema theory of discrete motor skill learning. *Psychological Review*, 82(4), 225-260.