KINETIC ASYMMETRY AND CENTER OF MASS DISPLACEMENT DURING JUMPS

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The purpose of this study was to determine the role of kinetic asymmetry on center of mass displacement in both mediolateral (COMd ML) and anteroposterior directions (COMd AP). Seventeen collegiate baseball players underwent weight distribution (WtD), and unloaded and loaded static (SJ) and countermovement jumps (CMJ). Concurrent kinetic and kinematic data were collected during the evaluation. Independent samples *t* tests were run to evaluate differences in COMd between the most and least asymmetrical athletes. WtD was not able to differentiate between values of COMd AP, but did for loaded conditions of COMd ML. Peak force and rate of force development (RFD) asymmetry appear to influence COMd, and RFD asymmetry appears to show the most differentiability between groups in terms of COMd ML. Kinetic asymmetry may result in undesirable displacement of athletes' COM during jumping.

KEYWORDS: bilateral strength asymmetry, weight distribution

INTRODUCTION: Bilateral strength asymmetry has been demonstrated in athletes (Bailey et al., 2014a, Bell et al., 2014, Knapik et al., 1991, Newton et al., 2006). The trend in asymmetry research is generally toward injury prediction or its relationship with performance (Bailey et al., 2013, Bazyler et al. 2014, Bell et al., 2014, Knapik et al., 1991). While the findings on the ability of strength asymmetry to predict injury remains somewhat unclear (Bennell et al., 1998, Buekeboom et al., 2000, Knapik et al., 1991), there does seem to be a consensus that force production asymmetry is detrimental to jumping and squatting performance (Bailey et al., 2013, Bazyler et al. 2014, Bell et al., 2014, Sato and Heise, 2012).

A computer simulation study completed by Yoshioka and colleagues (2011) produced results contradictory to those found by previous work (Bailey et al., 2013, Bell et al., 2014) that a bilateral strength asymmetry of 10% would not affect jump height. The simulation models were equated for overall strength, but the strength distribution was different. Their study suggested that the stronger side would make up for the deficit in the weaker side and jump height would not be affected. Interestingly, while the vertical component of the center of mass displacement (COMd) was not affected, there were differences in the mediolateral COMd. During the countermovement phase of the jump, the COM shifted towards the stronger side and then migrated towards the opposite side during the propulsive phase. This finding may indicate that force production asymmetry results in COMd in a mediolateral direction as well as the intended purely vertical direction. To the current author's knowledge, this has not been assessed on human subjects. Therefore, the purpose of this study was to determine the role of kinetic asymmetry on COMd in mediolateral and anteroposterior directions.

METHODS: Seventeen NCAA Division I baseball players between the ages of 18 – 23 years participated in this investigation after the completion of their competitive season. All athletes read and signed university approved informed consent documents prior to participation. All athletes underwent a standardized warm-up prior to testing, which consisted of 25 jumping jacks, one set of five mid-thigh pulls with a 20 kg bar, and three sets of five mid-thigh pulls with the bar loaded to 60 kg.

Force production asymmetry was evaluated by a static weight distribution (WtD) test and vertical ground reaction forces (vGRF) during jumps on two force plates (0.36 m x 0.36 m, PASCO Scientific PS-2142, Roseville, CA) embedded into a testing platform. Data were sampled at 1,000 Hz. Assessment of WtD was completed prior to the jump testing outlined below. WtD assessment was undertaken by athletes standing stationary on the force plates with their arms at their sides for approximately five seconds. Two trials were completed and the vGRF collected from under each foot for both 5s trials were averaged and used for analysis (Sato and Heise, 2012).

Following WtD assessment, athletes participated in squat jump (SJ) and countermovement jump (CMJ) testing, which included unloaded and lightly-loaded conditions. During jump testing athletes were restricted from performing an arm swing. This was done by the athletes holding a PVC pipe or a 20 kg bar behind their neck and was similar to the "high-bar" squat position. The weight of the PVC pipe, which was less than 1 kg, was considered insignificant. Before jump types and conditions, athletes performed warm-up trials at 50% and 75% of their perceived maximal effort. During the SJ athletes descended to a 90° knee angle which was measured with a goniometer, and waited to jump until the command was given. SJ trials with a visible countermovement on force-time curves were voided and then repeated. During the CMJ assessment, the countermovement depth was self-selected by each athlete. One minute of rest was allowed between trials. Two trials at each load and type were completed. Kinetic data from each force plate were used to derive the following variables: propulsive peak force (PF), peak velocity (PV), net impulse (NI), rate of force development (RFD), and time to peak force (TtoPF). These variables were then used to evaluate the magnitude of asymmetry. The Symmetry Index (SI) score (Sato and Heise, 2012; Shorter, Polk, and Rosengren 2008), was used to calculate the asymmetry magnitude. SI scores were calculated for each variable by inputting each into the following formula: SI = (larger value – smaller value)/total value * 100. Each SI score is a percentage, where values increasing from 0% denote larger asymmetry magnitudes. Variable SI scores were averaged for each jump type and condition and used for analysis.

COMd in both the mediolateral (ML) and anteroposterior (AP) directions were evaluated with an infrared 3D motion capture system utilizing six cameras (Vicon T40S Nexus software, ver. 1.85, Centennial, CO). Prior to jump testing, reflective markers were attached to each athlete according to the Vicon "Plug-in-Gait" model. All kinematic data were collected at 200 Hz and smoothed with a Woltring filter preprogramed into the motion capture data collection software (Woltring 1985). Based upon the COM velocity crossing zero, CMJs were divided into unweighing/eccentric (UW/Ecc) and propulsion (Pro) phases, which was then used in analysis.

Statistical analyses were completed with PASW software (SPSS version 20.0, An IBM company, New York, NY). Relative reliability was evaluated with intraclass correlation coefficients (ICC)(3,1). The kinetic SI variables used for COMd comparison were selected based on the results of factor analysis, which was used to condense the amount of variables. Factors with an eigenvalues greater than one were selected (Kaiser, 1960). Factor model suitability was evaluated utilizing the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and KMO values above 0.5 were selected (Kaiser, 1970). After factor analysis, the data were ranked in accordance with the selected factors. The median was then used to split each sample into two groups (most and least asymmetrical) and the median itself was excluded leaving two groups of eight athletes. Independent samples *t* tests were completed to assess group differences in COMd. As multiple *t* tests were run, a Holm-Bonferroni sequential adjustment was utilized to avoid type I error. Practical significance and difference magnitude was approximated with Cohen's *d* effect size estimates.

RESULTS: Acceptable relative reliability was noted for kinetic variables with ICC values being between 0.72 and 0.98. Kinematic variable ICCs were also acceptable with values between 0.82 and 0.99. Two factors were revealed for most jump types and conditions. Based on factor laodings, PF SI and RFD SI were selected. KMO results were all above 0.623. During the 0 kg

SJ, WtD was listed as a factor, but not in the loaded condition or in either of the CMJ conditions. Even though it was only noted as a factor during the 0 kg SJ, WtD was still selected on the basis of its ease of measurement.

Results of COMd ML and AP can be observed in Tables 1 and 2 for all jump types, conditions and phases. Statistical and practical differences in COMd ML were observed between groups based on WtD SI in the 20 kg SJ, groups based on PF SI and RFD SI in 0 kg CMJ propulsive phase, and the 20 kg CMJ eccentric phase. Practical differences were also observed for the groups separated by WtD SI, PF SI, and RFD SI in the 20 kg CMJ propulsive phase, as well as the RFD SI separated groups in the 20kg SJ. Concerning COMd AP, statistical differences were observed in the propulsive phase of the 0 kg CMJ when groups were separated by PF SI, but not in the loaded condition.

Table 1

Results of *t* tests between highest and lowest SI scores when sorted by WtD SI and PF SI. *P* values are reported and Cohen's *d* values are reported in brackets.

		WtD SI		**PF SI**	
		COMd ML	COMd AP	COMd ML	COMd AP
0 kg	SJ	0.660 (0.23)	0.147 (0.73)	0.670 (0.20)	0.745 (0.17)
	CMJ UW/Ecc	0.883 (0.08)	0.642 (0.24)	0.272 (0.57)	0.240 (0.60)
	CMJ Pro	0.394 (0.44)	0.450 (0.39)	0.007* (1.25)	0.009* (1.22)
20 kg	SJ	0.032* (1.04)	0.564 (0.30)	0.830 (0.11)	0.518 (0.34)
	CMJ UW/Ecc	0.771 (0.15)	0.980 (0.01)	0.826 (0.12)	0.870 (0.09)
	CMJ Pro	0.070 (0.90)	0.417 (0.42)	0.107 (0.81)	0.227 (0.62)

*Denotes statistical significance, initially set at *p*<0.05

Table 2

Results of *t* tests between highest and lowest SI scores when sorted by RFD SI. *P* values are listed and Cohen's *d* values are reported in brackets.

		RFD SI	
		COMd ML	COMd AP
0 kg	SJ	0.323 (0.51)	0.107 (0.81)
	CMJ UW/Ecc	0.502 (0.35)	0.549 (0.31)
	CMJ Pro	0.008* (1.23)	0.140 (0.75)
20 kg	SJ	0.11 (0.81)	0.092 (0.84)
	CMJ UW/Ecc	0.014* (1.16)	0.503 (0.35)
	CMJ Pro	0.090 (0.85)	0.331 (0.50)

*Denotes statistical significance, initially set at *p*<0.05

DISCUSSION: The purpose of this study was to determine if kinetic asymmetries influence COMd. The primary finding of the study was that both statistical and practical differences in COMd were found between groups of high and low asymmetry values. Following variable reduction with factor analysis, three factors were chosen (WtD SI, PF SI, and RFD SI). WtD does not appear to be a good way to differentiate between anteroposterior COMd, but may be for mediolateral COMd during loaded jump testing. This is evidenced by a lack of statistical significance and small effect size estimates in all jump types and conditions except the loaded SJ and propulsive phase of the CMJ. Although statistical significance was not found in the CMJ Pro phase 20 kg condition, a large effect size estimate was observed, indicating a practical difference between groups divided by WtD SI. Loaded jump assessments have been used previously to simulate a fatigued situation or to determine how an athlete responds to external loads (Bailey et al., 2014b). On the same basis, athletes with the largest WtD SI values may be more prone to producing unwanted movements during dynamic bilateral tasks when fatigued or when under a load. This may be of interest to coaches and those seeking a more economical route to evaluating asymmetry, as WtD can be measured quite cheaply with two scales. COMd in either direction may be larger in those who have larger PF SI during the CMJ propulsion phase. Asymmetry of PF SI during the SJ or unweighting and eccentric phase of the CMJ was not able to differentiate between large and small displacements in either direction. This may be related to the CMJ propulsion phase starting at a higher force from the eccentric contraction. RFD asymmetry appears to be the best predictor of mediolateral COMd and a modest predictor for anteroposterior COMd during bilateral jumps. Practically speaking, this could describe deviation of movement to mediolateral and anteroposterior directions when force was developed differently in simultaneous bilateral actions such as jumping or squatting. Further investigation should be conducted to enhance the knowledge of how RFD is related to a more vertically oriented COMd during the vertical jump task.

CONCLUSION: Kinetic asymmetry may result in unwanted displacement of the athlete during vertical jumping and possibly during training, leading to altered performance and adaptations. RFD asymmetries may be the best way to evaluate this phenomenon.

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