KINEMATIC PARAMETERS FOR LARGE TRUNK TWIST TORQUE OUTPUTS DURING THE BAR TWIST EXERCISE

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This study aimed to clarify the kinematic characteristics for large trunk twist torque outputs during a bar twist exercise, focusing on the angle and angular velocity of the trunk twist. Twenty-one healthy male college athletes performed the bar twist exercise. Kinematic and kinetic data were recorded using the Vicon system (250 Hz) and two force platforms (1000 Hz). The participants were divided into two groups based on the maximal trunk twist torque of an individual compared to the mean value of the all participants. The results revealed that participants who had a large trunk twist torque output showed a large trunk twist angle against the direction of rotation and a large negative trunk twist angular velocity. Therefore, during bar twist training, a maximal trunk twist angle and a large negative angular velocity at the countermovement motion could be effective in obtaining large trunk twist torque.

KEYWORDS: plyometrics, stretch-shortening cycle, angular velocity

INTRODUCTION: Trunk twist is fundamental movement to contribute the performance in various sports, including those requiring throwing and hitting (Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002). In these sports, a stretch-shortening cycle (SSC) occurs during trunk twist, which contributes to increase the force and power outputs of trunk twist muscles. Plyometrics is one of the training methods employed to improve force and power outputs produced during the SSC. An example is the bar twist exercise, in which an athlete supports the barbell shaft on the shoulders while in the standing position and rotates it horizontally (Radcliffe & Farentinos, 1999). Few studies have examined the kinetics of the trunk twist during this exercise (Takahashi, Yoshida, & Asai, 2018; Takahashi, Yoshida, Kariyama, Hayashi, & Zushi, 2016). For the isometric strength of the trunk twist, some studies showed that trunk twist torque decreased when the trunk rotated in the direction of rotation and increased when against the direction of rotation (Kumar, Narayan & Garand, 2002; Pope, Svensson, Andersson, Broman, & Zetterberg, 1987). Kumar et al. (1996) had demonstrated that the return to the neutral posture from a pre-rotated posture involved a significant recoil of the passive connective tissue and the recoil increases the torque when rotating against the direction of pre-rotation. According to these studies, the increase in the trunk twist torque was influenced by the trunk twist angle against the direction of pre-rotation. Therefore, evaluation of the kinematic parameters of the trunk twist movement during the bar twist exercise is important for understanding the development of force in and power capacity of the trunk. This study aimed to evaluate the kinematic characteristics for large torque and power outputs of the trunk twist during the bar twist exercise, focusing on the angle and angular velocity of the trunk twist.

METHODS: Twenty-one healthy male college athletes participated in this study: 7 throwers in track and field events, 6 baseball players, and 8 tennis players (age: 20.50 ± 1.89 years; height: 1.76 ± 0.05 m; and weight: 82.06 ± 19.89 kg (mean ± SD)). This study was approved by the Ethics Committee of the Institute of Health and Sport Sciences, University of Tsukuba, Japan. An informed consent was obtained from all participants. All participants performed the bar twist exercise; the steps are illustrated in Figure 1. First, the participants rotated a bar (length: 2.00 m; weight: 10.00 kg) clockwise; when the right side of the bar passed the mark (located at bar angle −75°), they immediately rotated the bar counter-clockwise with maximal effort.
The Vicon system (Vicon Motion System, Ltd.) was used to record the three-dimensional coordinates of 49 retro-reflective markers fixed on the body (47 points, Suzuki, Ae, Takenaka & Fujii, 2014) and on the outer end of the bar (2 points), with 12 cameras operating at 250 Hz. The ground reaction force was measured with two Kistler force platforms at 1000 Hz. The horizontal rotation angular velocities of the bar, upper trunk, pelvis, and trunk twist were calculated (Takahashi, Yoshida, Kariyama, Hayashi, & Zushi, 2016). Smoothing of the

coordinates was achieved using a Butterworth digital filter with optimal cut-off frequencies of 2.5–15 Hz, which were determined using the residual method. In the global coordinate system, the X, Y, and Z-axes represented the mediolateral direction, the anterior-posterior direction, and the vertical direction, respectively. The locations of the centre of mass and inertia of each segment were estimated based on the body segment parameters for Japanese athletes, as described by Ae (1996).
The torque of the trunk joint, which was modelled as the midpoint of the lower end of the right and left ribs, was calculated using the bottom-up approach of inverse dynamics. The joint torque power was determined as a dot product of the joint torque and its angular velocity. The angular impulse was calculated as the integrated amplitude of the joint torque curve.
Kinematic and kinetic data were divided into the countermovement phase (CP) and main phase (MP), based on the direction of bar rotation. The CP refers to the movement from the initiation of clockwise rotation to the point when the bar passed the mark. Following the CP, the MP is the counter-clockwise rotation of the bar, that is, from the moment the bar angular velocity exceeded 10°/s until it reached its peak value. The participants in this study were divided into two groups based on the maximal trunk twist torque of each participant and the mean value of the group (H group: individual value > mean value; L group: individual value < mean value). The time series data were normalized to the time of CP (0-75%) and MP (75-100%). A statistical analysis of these parameters was carried out using SPSS software (SPSS Inc.). A Student's t-test was used to detect differences in the means and repeatedly at each % time instance between the H group and L group. The Pearson's correlation coefficient was used to determine the relationships between torque and angular velocity of trunk twist. A p-value of < 0.05 was considered statistically significant.

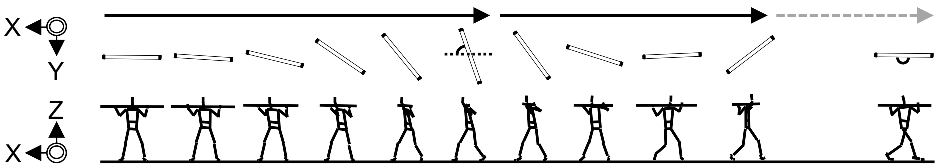

Figure 1: The steps of the bar twisting exercise and definition of each phase (CP and MP).

RESULTS: Figure 2 shows the ensemble averages of trunk twist angle, angular velocity, joint torque, and joint torque power for both H group and L group. Trunk twist angle in the H group was significantly larger than that of the L group during 83–100%. The trunk twist angular velocity in the H group was significantly lower than that in the L group during the normalized time duration of 57–68% and greater than that in the L group during 95–100%. The trunk twist torque in the H group was significantly lower than that in the L group during the normalized time duration of 24–41% and greater than that in the L group during 67–92%. The trunk twist

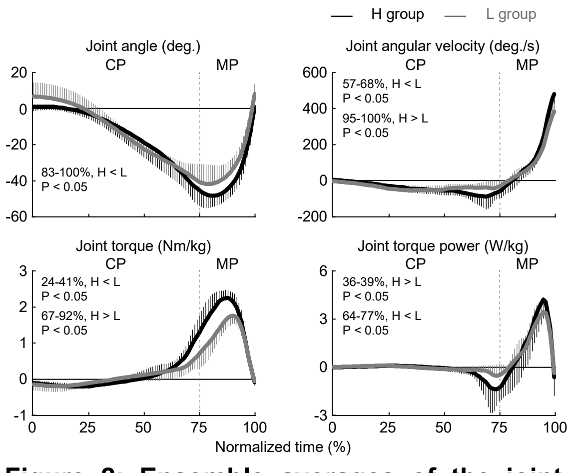

Figure 2: Ensemble averages of the joint angle, angular velocity, joint torque and joint torque power of trunk twist between the H group and L group.

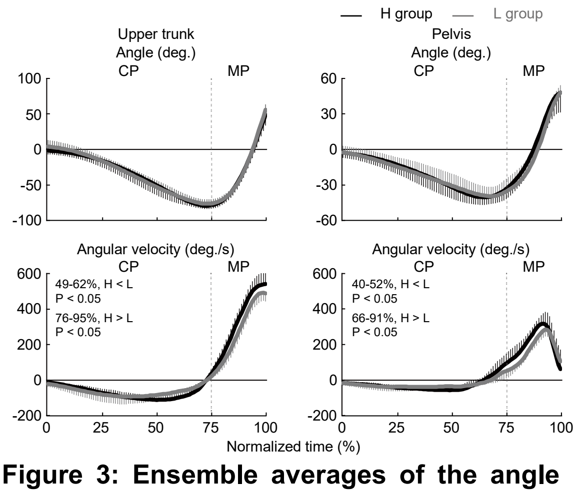

Figure 3: Ensemble averages of the angle and angular velocity of the upper trunk and pelvis between the H group and L group.

torque power in the H group was significantly lower than that in the L group during the normalized time duration of 64–77% and larger than that in the L group during 36–39%. Figure 3 shows the ensemble averages of the angle and angular velocity of the upper trunk and pelvis between the H group and the L group. The angle of the upper trunk and pelvis was not significantly different between the groups. The upper trunk angular velocity in the H group was significantly lower than that in the L group during the normalized time duration of 49–62% and greater than that in the L group during 76–95%. The pelvis angular velocity in the H group was significantly lower than that in the L group during the normalized time duration of 40–52% and greater than that in the L group during 66–91%.

Table 1 shows the maximal and minimal value of kinetics and kinematics variables during this experiment. The maximal values of trunk twist torque and angular velocity of the bar and trunk twist in the H group were significantly larger than those of the L group. The minimal value of the trunk twist angular velocity in the H group was significantly lower than that of the L group. Between the H and L groups, there were no significant differences in the maximal values of trunk twist torque power and angular velocity of upper trunk and pelvis; in the minimal values of the angular velocity of the bar, upper trunk, and pelvis; and in the minimal values of the trunk twist angle and angular displacement of trunk twist.

Table 1: Kinetic and kinematic variables in this experiment.

	Maximal value	
	Trunk twist torque (Nm/kg)	Trunk twist torque power (W/kg)
H group (n=11)	2.35 ± 0.19	4.46 ± 1.18
L group (n=10)	1.84 ± 0.20	3.73 ± 0.79
Differences	H > L (P < 0.05)	n.s. (P = 0.115)

	Minimal angular velocity (deg/s)			
	Bar	Upper trunk	Pelvis	Trunk twist
H group (n=11)	-134.50 ± 39.65	-124.41 ± 34.30	-71.33 ± 22.04	-120.89 ± 54.27
L group (n=10)	-107.70 ± 37.65	-103.11 ± 34.37	-54.63 ± 18.62	-80.41 ± 27.70
Differences	n.s. (P = 0.130)	n.s. (P = 0.172)	n.s. (P = 0.078)	H < L (P < 0.05)

	Trunk twist angle (deg)	
	minimal	Angular displacement
H group (n=11)	-49.61 ± 6.80	50.38 ± 8.30
L group (n=10)	-42.14 ± 10.47	50.04 ± 7.92
Differences	n.s. (P = 0.065)	n.s. (P = 0.925)

	Maximal angular velocity (deg/s)			
	Bar	Upper trunk	Pelvis	Trunk twist
H group (n=11)	625.55 ± 68.65	547.69 ± 65.92	331.43 ± 51.70	481.57 ± 94.84
L group (n=10)	550.21 ± 47.52	500.65 ± 44.55	289.66 ± 40.83	383.35 ± 44.52
Differences	H > L (P < 0.05)	n.s. (P = 0.073)	n.s. (P = 0.055)	H > L (P < 0.05)

Figure 4 shows the correlation between the minimal value of trunk twist angular velocity and the maximal trunk twist torque. There was a significantly negative relationship between these variables.

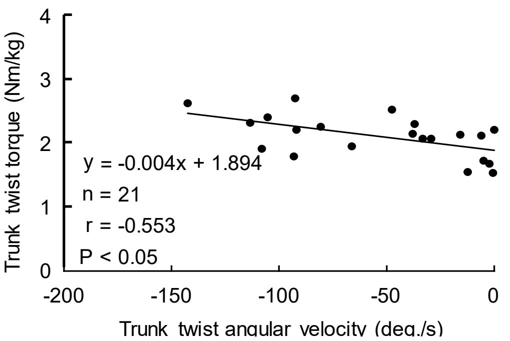

Figure 4: Correlation between minimal angular velocity and maximal joint torque of the trunk twist.

DISCUSSION: The maximal angular velocity of the bar and trunk twist in the H group was significantly larger than those of the L group (Table 1). Furthermore, trunk twist torque in the H group was significantly larger than that of the L group from the end of the CP to the MP (Figure 2); similar results were observed for the maximal trunk twist torque (Table 1). These results indicated that large trunk twist torque outputs contribute to the large angular velocity during the bar and trunk twist exercise. In this study, the trunk twist angle in the H group was significantly greater than that in the L group (Figure 2). Thus, a wide trunk twist angle against the pre-rotation direction contributes to a large trunk twist torque output. These results were similar to those reported in the previous studies (Kumar, Narayan & Garand, 2002; Pope, Svensson, Andersson, Broman, & Zetterberg, 1987). However, with respect to the angular displacement during trunk twist, no significant differences were observed between the H group and L group. Therefore, larger angular displacement is not important for large trunk twist torque outputs.

The trunk twist angular velocity was negative from the end of the CP to the start of the MP and subsequently became positive during the MP (Figure 2). In this exercise, the pelvis angular velocity was positive and the upper trunk angular velocity negative from the end of the CP to the start of the MP (Figure 3). This result indicated that the SSC of the trunk twist not only occurs due to the countermovement motion of the bar rotation but also defines the difference in the angular velocities of the pelvis and the upper trunk. In SSC, more cross-bridges result during the subsequent concentric contraction than when a muscle contracts without pre-stretch (van Ingen Schnau, 1984). In this study, there was a significantly negative relationship between the minimal value of the trunk twist angular velocity and the maximal trunk twist torque (Figure 4). Therefore, the H group with the lower trunk twist angular velocity showed the SSC, resulting in a trunk twist torque greater than that in the L group. The minimal value of trunk twist angular velocity is at the boundary between the CP and MP (Figure 2), where the angular velocities of the pelvis was positive and the upper trunk negative. Thus, the negative value of the trunk twist angular velocity resulted from the increase in the pelvis angular velocity. Therefore, the change of pelvis angular velocity from the end of the CP contributes to the large negative trunk twist angular velocity and large trunk twist torque outputs due to the effects of the SSC movement. Pelvis rotation is occurred by generated force and power from the lower extremities. Future study is needed to clarify the role of lower extremity for trunk twist torque output.

CONCLUSION: This study aimed to clarify the kinematic characteristics for large torque and power outputs of the trunk twist during the bar twist exercise, focusing on the angle and angular velocity of the trunk twist. Twenty-one healthy male college athletes performed the bar twist exercise. The Participants were divided into the H group or L group based on whether the maximal trunk twist torque of individuals was larger than the mean value of the all participants. The study revealed that: (1) Participants with a large trunk twist angle against the direction of rotation when the MP was started achieved large trunk twist. (2) Large negative trunk twist angular velocity leads to maximal trunk twist torque outputs due to the occurrence of SSC. Therefore, when athletes perform bar twist training to improve the torque outputs of the trunk twist during the pitching and hitting sports, a large trunk twist angle and large negative angular velocity during the countermovement motion may be effective for obtaining large trunk twist torque outputs.

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