FORCE AND POWER OUTPUTS OF TRUNK-TWIST DURING BAR TWIST EXERCISE - INFLUENCE OF LENGTH AND MASS OF BARS

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The purpose of this study was to investigate force and power outputs during bar twist exercises using barbell shafts, considering various moment of inertia (MOI), corresponding to changes in the bar length and mass. Twenty-one male college athletes performed the bar twist exercise using five barbell shafts: one normal barbell shaft, two long barbell shafts (with changes only in the length), and two heavy barbell shafts (with changes only in the mass). Kinematic and kinetic data were recorded using the Vicon system (250 Hz) and two force platforms (1,000 Hz). The results obtained in this study revealed that: (1) Peak angular velocity of bar and upper trunk for the long barbell shaft condition was higher than the heavy barbell shaft condition; (2) For higher MOI, the trunk-twist torque was higher; and (3) Even when the barbell shaft had equal MOI, the heavy bar showed higher trunk-twist torque prior to the bar rotation.

KEY WORDS: stretch-shortening cycle, plyometric training, joint torque

INTRODUCTION: The human trunk has large skeletal muscles, and has an important role in athletic performance (Hedrick, 2000). Trunk-twist movement is fundamental in various sports, including those requiring throwing and hitting. In these sports, a stretch-shortening cycle (SSC) occur in trunk-twist movement, which contribute to improving the athletic performance (Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002). Plyometric training is one of the training methods for improving force and power outputs accompanying the SSC movement. The bar twist exercise, in which an athlete supports the barbell shaft on the shoulders in the standing positon and rotates it horizontally is one type of plyometric training of the trunk-twist (Radcliffe & Farentinos, 1999). The load resistance in this exercise is determined by the moment of inertia (MOI) of the barbell shaft. The MOI of the barbell shaft depends on the length and mass of the bar. So far, few studies have examined the influence of MOI on the characteristics of force and power outputs during this exercise (Takahashi, Yoshida, Kariyama, Hayashi, & Zushi, 2016). In SSC movement, more cross bridges will be available during the subsequent concentric contraction than when a muscle contracts without pre-stretch (van Ingen schnau, 1984). Therefore, clarifying the kinetic parameters in the prestretch movement is important to understanding the development of force and power capacities of the trunk. The purpose of this study was to clarify the characteristics of force and power outputs during the bar twist exercise, using barbell shafts with various MOI, corresponding to changes in the bar length and mass.

METHODS: Twenty-one healthy male college athletes participated in this study: Seven throwers in track and field events, six baseball players, and eight tennis players (mean ± S.D. age: 20.50 ± 1.89 years, height: 1.76 ± 0.05 m, and weight: 82.06 ± 19.89 kg). This study was approved by the Ethics Committee of the Institute of Health and Sport Sciences, University of Tsukuba, Japan. All participants performed the bar twist exercise, as illustrated in Figure 1. First, the participant rotated the bar clockwise; when the right side of the bar passed the mark (located at bar angle −75°), he immediately rotated the bar counterclockwise. Five bars with different characteristics (length and mass) were used in this experiment (Table 1). The normal bar (NB) and the two long bars (LB) were iron bars with the following respective length and mass: 2.00 m and 10.00 kg (NB), 2.83 m and 10.00 kg (LB2), and 3.46 m and 10.00 kg (LB3). Two heavy bars (HB) were assembled by adding to the NB two loads at a distance of 0.80 m from the bar center. Thus, the length and mass of the HB were 2.00 m and 15.21 kg (HB2) and 2.00 m and 20.42 kg (HB3). LB2 and HB2 have the same MOI; similarly, LB3 and HB3 have the same MOI. The MOI of each bar was calculated using the following equation:

$$MOI = 1/12 \cdot mb \cdot Lb^2 + (ml \times Ld^2) \cdot 2$$

where mb is the mass of the bar (kg), Lb is the length of the bar (m), ml is the mass of the added load (kg), and Ld is the distance of the added load from the bar center (m).
The three-dimensional coordinates of 49 retro-reflective markers fixed on the body (47 points, Suzuki, Ae, Takenaka & Fujii, 2014) and outer end of bar (2 points) were recorded by the Vicon system (Vicon Motion System, Ltd.), using twelve cameras operating at 250 Hz. The ground reaction force was measured with two Kistler force platforms at 1,000 Hz. The horizontal rotation angular velocity of the bar, upper trunk, pelvis, and trunk-twist were calculated (Takahashi, Yoshida, Kariyama, Hayashi, & Zushi, 2016). Smoothing of the coordinates was achieved by 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 respectively represent the mediolateral direction, the anterior-posterior direction, and the vertical direction. The location of the center of mass and inertia of each segment was estimated based on the body segment parameters for Japanese athletes, as described by Ae (1996). The torque of the trunk joint, which was modeled as the middle point 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 time from the initiation of clockwise rotation of the bar until the bar passed the mark defined the CP. The MP followed the CP and consisted of the counterclockwise rotation of the bar from the moment the bar angular velocity exceeded 10°/s until it reached peak value. The time during the CP and MP were measured. A two-way analysis of variance with Bonferroni post hoc contrasts was used to detect differences in the means. The *P* value (< 0.05) was considered statistically significant.

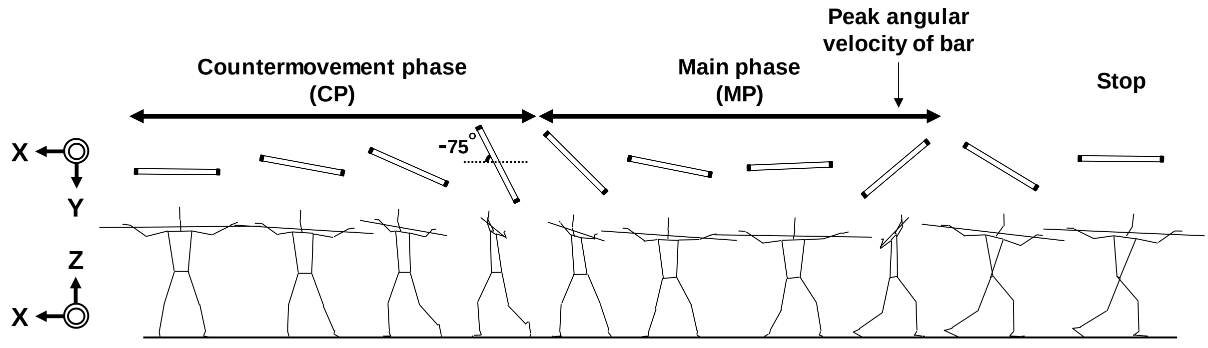


Figure 1: The attempt of bar twisting exercise and definition of the phase.

Table 1: Detail of using barbell shafts in this study.

	Bar		Load		Total mass (kg)	Moment of inertia (kgm^2)
	Length (m)	Mass (kg)	Distance from bar center (m)	Mass (kg)		
NB	2.00	10.00	–	–	10.00	3.33
LB2	2.83	10.00	–	–	10.00	6.67
LB3	3.46	10.00	–	–	10.00	10.00
HB2	2.00	10.00	0.80	2.60 × 2	15.21	6.67
HB3	2.00	10.00	0.80	5.21 × 2	25.42	10.00

RESULTS: Figure 2 shows the peak angular velocity of the bar, upper trunk, pelvis, and trunk-twist for each load. There were significant interaction effects between the tasks (LB-HB and MOI) in the bar and upper trunk. The LB angular velocity were higher than those for HB.

With an increasing MOI, the peak angular velocity significantly decreased. The pelvis and trunk-twist did not exhibit significant interaction effects between the tasks. With an increasing MOI, the peak angular velocity of pelvis and trunk-twist significantly decreased. However, there was no difference for pelvis and trunk-twist between LB and HB.

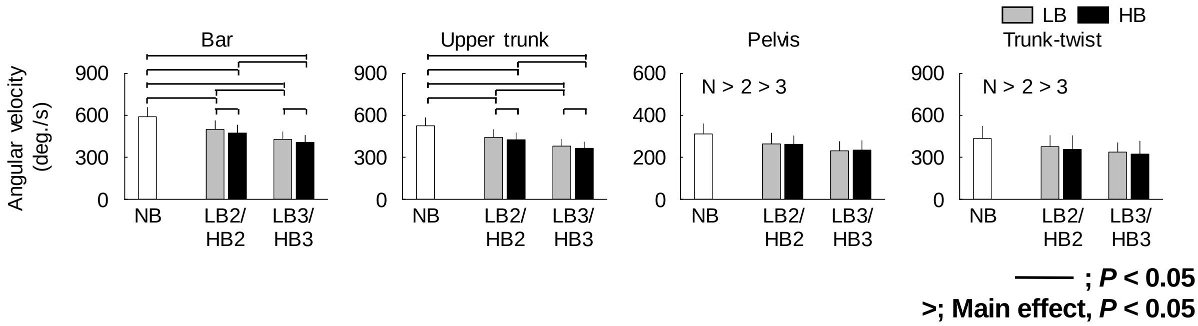


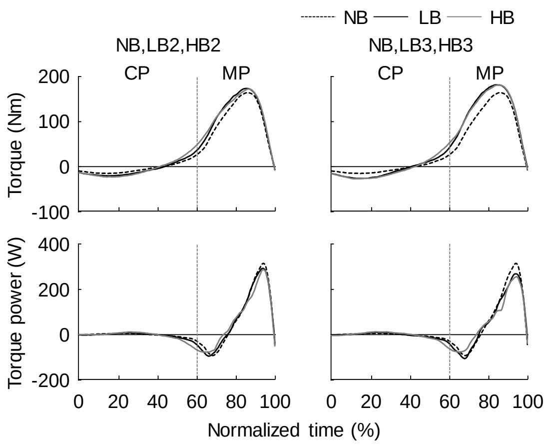
Figure 2: Peak angular velocity of bar, upper trunk, pelvis and trunk-twist in each bar.

Table 2 shows the time to bar rotation. There were no significant interaction effects between the tasks in CP and MP. In CP, there was no difference between LB and HB. NB was shorter than 2LB/HB and 3LB/HB. The time of bar rotation using LB was significantly shorter than using HB. With an increasing MOI, the time of bar rotation significantly increased.

Table 2: Time of bar rotation in each barbell shafts.

	Time (s)					Interactions	Main effects		Difference	
	NB	LB2	LB3	HB2	HB3	(F value)	LB-HB	MOI	LB-HB	MOI
CP	1.25 ± 0.33	1.32 ± 0.38	1.41 ± 0.32	1.30 ± 0.38	1.48 ± 0.48	1.19	0.47	7.36	n.s.	N , 2 < 3
MP	0.45 ± 0.08	0.52 ± 0.08	0.60 ± 0.09	0.55 ± 0.09	0.61 ± 0.08	3.00	5.37	182.48	L < H	N < 2 < 3

Figure 3 shows the averages of the joint torque and joint torque power of trunk-twist in each load. In joint torque, the positive values indicate the direction of the torque to rotate the trunk counterclockwise. The joint torque demonstrated a positive value prior to MP. With increasing MOI, the peak joint torque increased (*P* < 0.05); however, there were no significant differences between LB and HB. In joint torque power, there was no significant difference between LB and HB, or among the MOI.
Figure 4 shows the integrated value of trunk-twist torque in CP and MP. In CP, there were significant interaction effects between the tasks. The LB showed higher angular impulse than those of HB. With an increasing MOI, the angular impulse significantly increased. In MP, there were no significant interaction effects between the tasks. LB showed higher angular impulse than HB. With an increasing MOI, the angular impulse significantly increased.



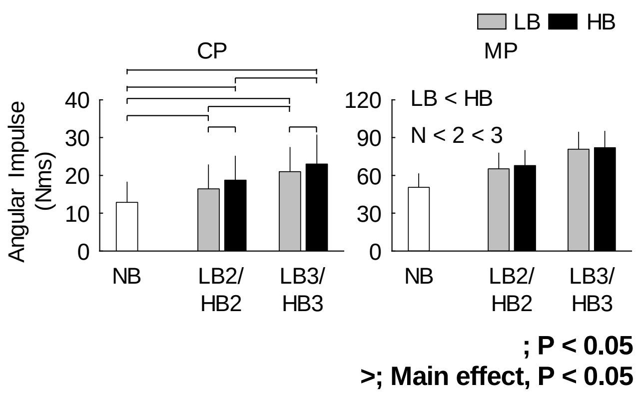


Figure 3: Joint torque and joint torque power of trunk-twist in each bar.

Figure 4: Averages of the integrated value of trunk-twist torque.

DISCUSSION: Peak angular velocity of the bar, upper trunk, pelvis and trunk-twist decreased with increasing MOI (Figure 3). In contrast, the integrated value of trunk-twist torque significantly increased with increasing MOI (Figure 4). These results are in line with those of previous research on the relationship between joint torque and joint angular velocity during the squat exercise with various loads (Kipp, Harris & Sabick, 2011). The MOI is a resistance to the rotary movement; thus, activity of the trunk muscles is required to be increased in order to generate higher joint torque to rotate the barbell shafts with higher MOI, such as in LB3 and HB3. The trunk-twist torque power demonstrated no significant difference among the different MOI. Joint torque power was determined as a dot product of the joint torque and angular velocity. Thus, the opposite change in joint torque and angular velocity of trunk-twist with increasing MOI represented no difference in trunk-twist torque power. Considering the difference between LB and HB, the peak angular velocity of bar and upper trunk in LB were higher than in HB (Figure 2). Nevertheless, the integrated value of the trunk-twist torque in HB was larger than that of LB in both CP and MP (Figure 4). The time of MP in HB was higher than that of CP, and thus, the longer duration affected the increase in the integrated value of the trunk-twist torque in HB. In contrast, even when the time of CP showed no difference between LB and HB, the integrated value of the trunk-twist torque in LB was higher than that of HB in CP. This result indicates that HB2 and HB3 are, respectively, more difficult to rotate compared to LB2 and LB3, even though the MOI of LB2 and HB2, and LB3 and HB3 are the same. In the bar twist exercise, participants rotated the bar as a clockwise rotation to counterclockwise rotation against the inertia of the rotating bar and gravitational force, supporting the barbell shaft on their shoulders during the bar rotation. Consequently, activity of trunk muscles, which likely play a stabilizer role (Kumar, Narayan & Garand, 2003), may be increased using the HB, contributing to increased trunk-twist torque.

CONCLUSION: The study clarified the characteristics of force and power outputs during the bar twist exercise using barbell shafts with various MOI, by changing the bar length and mass. The results revealed that: (1) The peak angular velocity of LB was higher than of HB, and the time to peak angular velocity was lesser. (2) For higher MOI, the trunk-twist torque was higher. (3) Even when the barbell shafts had equal MOI, HB showed higher trunk-twist torque in prestretch prior to the bar rotation. Therefore, when athletes perform trunk-twist training, using HB loads could be effective to improve trunk-twist torque.

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