KINEMATIC ANALYSIS OF CABLE FORCE DURING HAMMER THROWS WITH HEAVIER IMPLEMENTS

Kenichi Hirose[1], Keigo Ohyama Byun[2] and Mitsugi Ogata[2]
Graduate School of Comprehensive Human Science, University of Tsukuba, Tsukuba, Japan[1]
Faculty of Health and Sport Science, University of Tsukuba, Tsukuba, Japan[2]

The purpose of this study is to compare the differences in cable force between throws with a competition hammer (7.26 kg) and a heavier hammer (8.0 kg). Sixteen male hammer throwers threw the competition and heavier hammers, and three-dimensional motion analyses were conducted. The maximum cable force of the heavier hammer was significantly higher than that of the competition hammer during the double support phase of the 3rd and 4th revolutions. This indicates that throws with the heavier hammer cause a load increase during a particularly important phase of the hammer head's acceleration. This suggests that throws with a heavier hammer can be an effective training method for improving specific strengths to accelerate of the hammer's head.

KEY WORDS: speed-resisted training, three-dimensional analysis, calculated force

INTRODUCTION: The hammer throw is a track and field event. The hammer has a 7.26 kg (16 lb) ball-shaped head to which a cable with a handle is attached (the total length of the hammer is approximately 1.2 m from the ball to the inside of the handle). Because turn movement accelerates the hammer's head, the hammer thrower is required to maintain traction against the centrifugal force (Okamoto, 2007). Dapena (1982) reported that cable force is 2750 N in a throw of 67.50 m and exceeds 3000 N in a throw of 75.33 m (Murofushi et al., 2005). To accommodate this force, hammer throwers require specific strength (McAtee et al., 2006). Speed-resisted training (e.g. uphill running and swinging with a heavy bat) is a method for increasing external load and a means of training for specific strengths (Zatsiorski & Kraemer, 2006). In throwing events, overweight implements have been used (Bondarchuk et al., 1977). Similarly, in the hammer throw, heavier hammers are used in training instead of competition hammers (Bingisser, 2010, Bondarchuk, 1981, McAtee et al., 2006). Bartonietz (1994) examined the maximum cable force of throws with heavier hammers and found that they caused an increase in cable force. However, this analysis only addressed maximum cable force. Hence to gain a further understanding of load properties throughout the throw with a heavier hammer, a more detailed analysis of the kinematics of the throw was needed. Therefore, the purpose of this study was to compare the differences in the cable force between throws with the competition hammer and heavier hammer.

METHODS: The participants were sixteen male hammer throwers (age, 22.3 ± 2.8 years; height, 1.79 ± 0.05 m; body mass, 103.8 ± 13.3 kg; personal best, 60.24 ± 5.04 m). In the reports of speed-resisted training in throwing events (e.g. shot put and javelin throw), the recommended range of increased weight is between 5% and 20% over the competition weight (Kanishevsky, 1984; Konstantinov, 1979). Considering these reports, the weight of the heavier hammer was determined to be 8.0 kg. Participants threw the competition hammer (7.26 kg) and heavier hammer (8.0 kg) with maximum effort. Utilizing three high-speed video cameras (300Hz), the three-dimensional coordinates of the hammer's head and handle were obtained by means of the direct linear transformation method. The cable force (F) was calculated using the formula for centrifugal force ($F = mV^2/r$), where m is hammer weight, V is hammer velocity and r is the radius of curvature. The radius of curvature was calculated using the method employed by Fujii et al. (2008). The coordinate data were smoothed with a Butterworth low-pass digital filter. Cut-off frequencies ranging from 5.0 to 8.0 Hz were determined by the residual analysis proposed by Winter (2004).

Turn motion was divided into stages by foot contact events (Figure 1). R-off is the instant of right foot takeoff from the ground and R-on is the instant of right foot ground contact. During each turn, there is a double support phase (DSP) when both feet are on the ground and a single support phase (SSP) when only the left foot is on the ground. Time-series data were normalized by the time of the turn phase and then averaged at every 1%. Each turn was divided into 2 phases (SSP and DSP): The first half (SSP) began at R-off and ended at R-on and the second half (DSP) began at R-on and ended at R-off. Each phase was set as 50%.

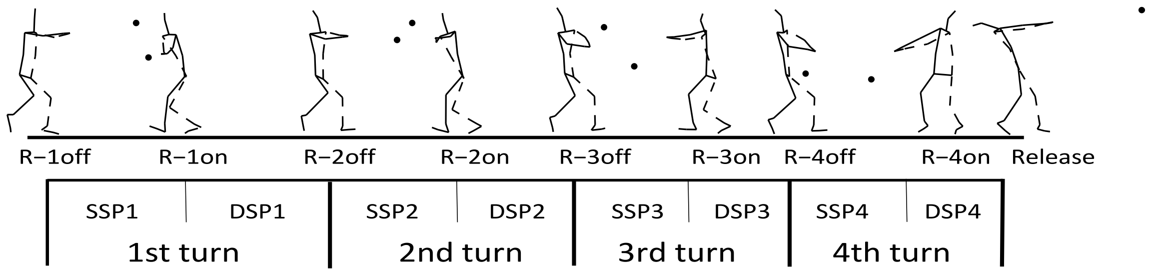

Figure 1: Definition of turn phases.

RESULTS: Table 1 shows the maximum cable force of each turn phase (from SSP1 to DSP4). The maximum cable force of the throw occurred during DSP4, and the maximum cable force of the throw in each phase with the heavier hammer was significantly higher than that of the throw with the competition hammer during DSP3 and DSP4.
Figure 2 shows the participants averaged patterns for cable force and vertical displacement of the hammer's head in the throw with the competition hammer and heavier hammer. Four oscillations occurred in cable force corresponding to the four turns. In each turn, the peaks in cable force occurred when the hammer was at its lowest point. Conversely, the minimum values of cable force in each turn appeared when the hammer was at the highest point. The cable force of the heavier hammer showed higher peaks during 80%-90%, 170%-180%, 270%-290% and 370%-390% normalized time, near the lowest points of the intervals. The cable force of the heavier hammer during the 190%-240% and 290%-330% interval remained high. During this phase, the cable force decreased and the vertical coordinates increased in the hammer's head for both the competition and heavier hammers.

Table 1: The maximum cable force of the competition hammer and heavier hammer during each turn phase.

	Cable force (N)		
Phase	Competition hammer (7.26kg)	Heavier hammer (8.0kg)	p-value
SSP1	725.9±117.9	707.3±117.8	0.250
DSP1	1092.1±130.0	1104.5±129.4	0.531
SSP2	1130.9±132.0	1110.5±157.5	0.404
DSP2	1545.3±145.6	1550.9±147.0	0.810
SSP3	1531.8±141.6	1540.0±146.8	0.778
DSP3	1910.1±177.8	1954.8±153.1	0.033*
SSP4	1811.8±186.4	1862.5±165.1	0.079
DSP4	2287.1±191.6	2339.9±163.6	0.006**

*:p<0.05, **:p<0.01

DISCUSSION: In throws with both hammers, the maximum cable force appeared at the end of the turn phase (DSP4). This finding supports Murofushi et al. (2007) and Brice et al. (2008). Therefore, the throwers gradually increased the cable force of the hammer's head through the 4 turns. Table 1 shows that during DSP3 and DSP4 of throws with the heavier hammer, the throwers experienced greater cable force than during throws with a competition hammer. Therefore, throws with the heavier hammer were confirmed to be an appropriate training method for speed-resisted training.

Throwers apply force by exploiting gravity from the high to low point of the path (Brice et al., 2008). Assuming a pendulum model, Ohta et al. (2009) noted that pulling the handle near the lowest point leads to effective acceleration of the hammer's head. The current study shows that cable force increased near the lowest point of the throw with the heavier hammer (Figure 2), which is a particularly important phase of the hammer head's acceleration. Therefore, throws with a heavier hammer are useful for improving the specific strengths and skills necessary to accelerate the hammer's head.

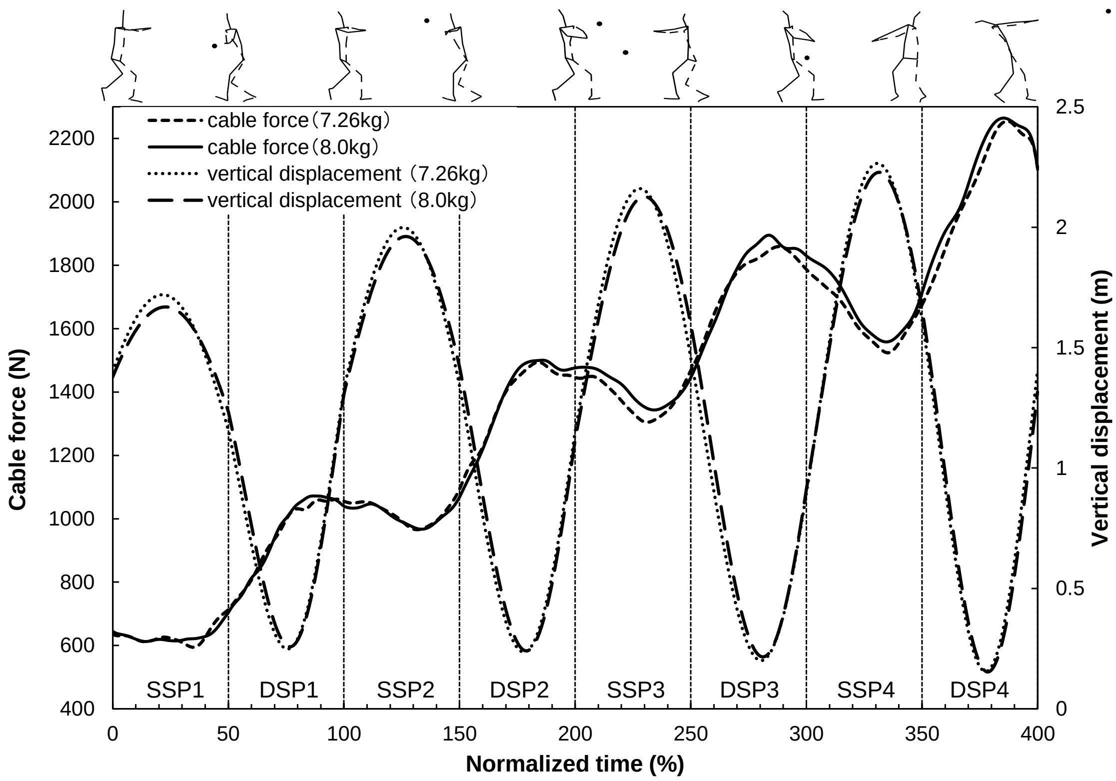

Figure 2: Averaged patterns of the sixteen participants for cable force and vertical displacement of the hammer's head in the throw with the competition hammer and heavier hammer.

CONCLUSION: The current study shows that the maximum cable force increased significantly in the heavier hammer throughout the throw. In addition, the maximum cable force in the turn phase with the heavier hammer was increased significantly during DSP3 and DSP4. This indicates that throws with the heavier hammer cause a load increase during a particularly important phase of the hammer head's acceleration. This suggests that throws with the heavier hammer can be an effective training for improving specific strengths to accelerate of the hammer's head.

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