A THREE-DIMENSIONAL MOTION ANALYSIS OF TWO-HANDED AND WAIST BELT PULLING BACKWARD EXERCISES IN ELITE TUG OF WAR ATHLETES

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In order to find the benefits of the waist belt (WB) in Tug of War (TOW) sport, the purpose of this study was to compare kinematic differences between two-handed (TH) and WB pulling backward exercises. The team that holds the gold medal record for the World Indoor TOW Championships 2004 participated in this study (N=20). According to three-dimensional video analysis procedures using the direct linear transformation analysis method, the mean body center of mass (COM) displacement during TH and WB trials were 0.7m and 1.45m, respectively. Moreover, the mean COM speed of WB was approximately 1.6 times faster than that of TH. These results suggest that the WB had the efficacy to accomplish a given task in the pulling backward exercise. Therefore it is concluded that WB might be one of useful equipments in the TOW sport.

KEY WORDS: Tug of War, dynamic pulling exertion, DLT.

INTRODUCTION: Although TOW has been considered as one of the oldest sports over the world, little study exists focused on either indoor or outdoor TOW. Pulling backward exercises in TOW contest can be divided into three phases, namely "drop", "hold" (photo1) and "drive" phase (photo2). Generally, a team that keeps the drive phase until the end of the contest wins. The pulling supported at a waist (WB) has been seen in labors at work places, such as an inshore fishery, yet the effects of WB have not been investigated. Therefore, the purpose of present study was to compare kinematic differences between WB and two-handed (TH) pull in the drive phase to investigate the benefits of the waist belt. This information will be beneficial for the development of a useful piece of equipment using WB' s mechanism for TOW sport.

METHODS: The team that holds the gold medal record for the World Indoor TOW Championships 2004 participated in this study (Table1). The force data during the drive phase were collected from the twenty subjects. Kinematic data for three of the 20 players during drive phase were obtained. Each subject wore TOW shoes (TOR107, Asics, Japan) and was required to perform a static TH pull at his maximal effort in order to determine the loads during drive phase, which were 70% of static maximal loads (Table2) (Yamamoto H. et al., 1997). Each subject performed TH and WB pull in the drive phase at his maximal effort. Subjects were instructed to pull for 5 seconds. The setting of pulling height was 60cm which was considered the approximate height in a contest of TOW. Paired t- test (a=0.05) was used to examine differences of data between TH and WB in statistical analysis. All trials were performed on the indoor TOW lane with official rope against the Tugging machine that allowed for adjustments in levels of load and provided the horizontal resistance (TUGMAN, Showa Electric Wire & Cable Co., LTD, Japan). The load cell (TCLP-200KA, Tokyo Sokki Kenkyujo, Co., LTD, Japan), containing a strain gauge force transducer was set between the rope and the tugging machine, measured the force applied. The forces amplified by the Strain amplifier (6M46, San-ei Instrument Co., LTD, Japan) lead into the computer (VAIO PCG-GRX90/P, SONY, Japan) using the software (Wad system ISF-6E, DKH, Japan) which converts analog data into digital data and collects time series force displacement data. The three digital video cameras operating at 30 frames per second were placed in three different directions to film movement of subjects during trials. The three-dimensional motion analysis system (Frame-DIAS for Windows, DKH, Japan) was used to digitize the anatomical landmarks of the body. The direct linear transformation (DLT) method of motion analysis for 3-D space reconstruction from 2-D images was used. The waist belt was usually used as a rescue equipment.

Table 1 Physical characteristics of subjects (n=20).

	Age (yrs)	Height (cm)	Weight (kg)	Experience (yrs)
Mean	28.3	174.4	71.9	5.4
SD	3.3	4.3	6.0	1.7

Table 2 Static pulling forces of subjects (n=20).

	Maximal force (N)	70% maximal force (N)
Mean	1580.1	1106.1
SD	19.9	136.2

RESULTS AND DISCUSION: The results of the comparison between TH and WB maximal pulling forces applied to the tugging machine during the drive phase were presented in Figure1. The correlations between TH forces produced and WB forces produced were significant (0.701). Although the force produced by 20 subjects did not differ significantly ($p<0.05$), more force was produced by WB than TH without using upper limbs.

Table3 shows the stride length, stride frequency and walking speed in TH and WB trials during pulling backward exercises. The results from this study showed that the speeds of backward walking were 0.2ms-1 in TH and 0.3 ms-1 in WB trials. The stride lengths in TH and WB were 0.2m each, and the stride frequencies were 1.4steps/s and 1.6steps/s respectively. Concerning the same stride length in TH and WB, an increase in walking speed during WB trials was due to an increase in stride frequency.

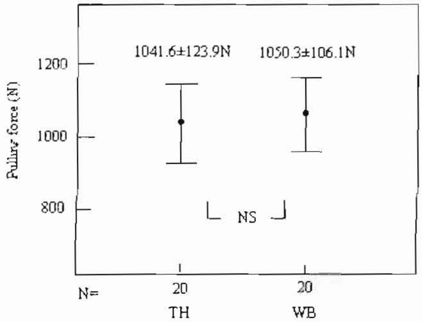

Figure 1: The mean maximal pulling forces in TH and WB trials during the drive phase (N).

Table 3 Stride length, stride frequency and walking speed in TH and WB trials during the drive phase.

	TH	WB
Stride length (m)	0.2	0.2
Stride frequency (steps/s)	1.4	1.6
Walking speed (m/s)	0.2	0.3

Table 4 Stance and swing phases in TH and WB trials (%).

	Maximal force (N)	70% maximal force (N)
Mean	1580.1	1106.1
SD	19.9	136.2

Figure 2 represents the lower limb joint angler displacements in right legs during TH and WB trials. The remarkable differences between TH and WB were smaller mean hip joint angle and a smaller range of change in knee joint angle during WB trials.

Figure 3 shows body center of mass (COM) displacement in X axis which represents the movement in a sagittal plane during TH and WB trials. The displacement of COM in X axis during TH and WB trials in 5 seconds were 0.7m and 1.45m respectively. In other words, the COM during WB trial moved approximately two times more than that of TH in the sagittal plane. The speed of COM displacements in composition during TH and WB trials was shown in Figure4. The mean COM speed in composition during TH and WB trials were 0.21±0.09ms-1 and 0.34±0.08 ms-1 respectively. The mean COM speed of WB was about 1.6 times faster than that of TH. The greater changes in speed of COM during TH trials can be seen in Figure4. On the other hands, small changes in speed of COM during WB trials can be seen and there is a tendency to increase speed

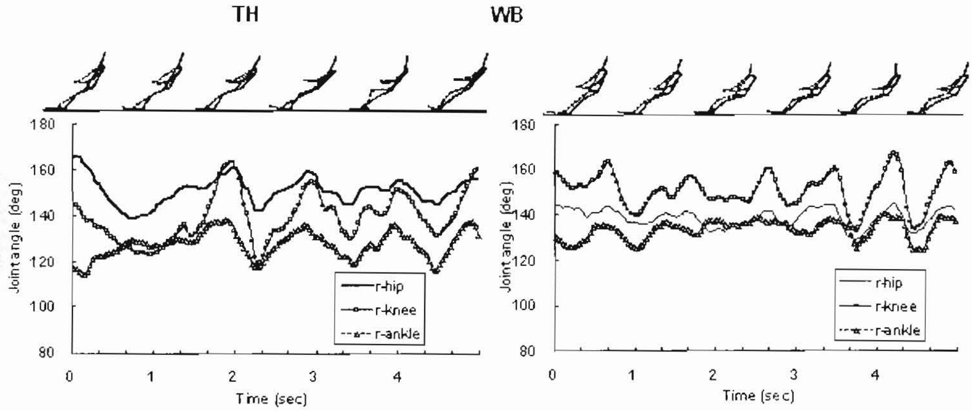

Figure 2: The lower limb joint angler displacements in right leg during TH and WB trials (deg).

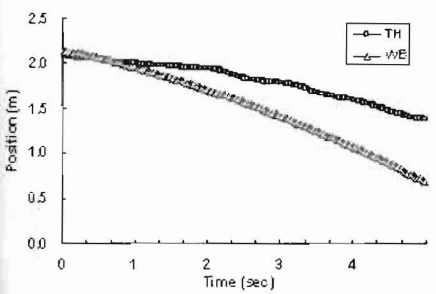

Figure 3: The displacements of COM in X axis during TH and WB trials (m).

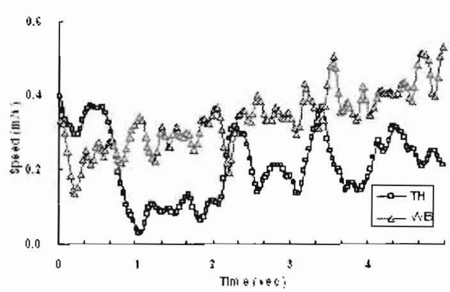

Figure 4: The speed of COM displacements in composition during TH and WB trials (m/s).

CONCLUSIONS: Since there was no significant difference between mean maximal forces of TH and WB trials in the drive phase, it could be assumed that WB would produce a pulling force no less than during a TH trial without using upper limbs. In addition, the backward walking speed during WB trials was 1.5 times faster than that of TH. And also, the mean speed of COM during WB trials was 1.6 times faster than TH. These results suggest that the WB had the efficacy to accomplish a given task in the drive phase. Therefore it is concluded that WB might be a useful piece of equipment for TOW sport.

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Photo 1: The youngest female TOW puller in the world during "hold" phase.

Photo 2: Kanazawa Rescue Team, 2004 Indoor TOW World Champion, during "drive" phase to victory.