BIOMECHANICAL CONSIDERATIONS OF PULLING FORCE IN TUG OF WAR WITH COMPUTER SIMULATION

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The purpose of this study was to investigate pulling force in tug of war in accordance with the changes of the tuggers' posture using the computer simulation, and considering the characteristics of human body such as body height, body weight, and holding height. As the model of human body, a 3-segmented rigid multibody system was made, which had three movable joints. After modeling, the validity of the model was verified by experimental data. As a result, pulling force was proved to be changed by the posture of the tugger, and increased by 2.8kg per 1 degree decrease in body inclination. Finally, it was found out that the maximum pulling force could be exerted in a certain posture of the tugger.

KEY WORDS: tug of war, pulling force, computer simulation

INTRODUCTION: The biomechanical computer simulation makes analyses possible without the high cost of analysis device. Besides, it decreases the time that is consumed for experiments or inputting biomechanical data, and gets rid of the danger at experiments. This study was focused on the pulling force and the posture of the tugger in the indoor tug of war.. The pulling force is determined by the object height, and the posture of the tugger (Matsuno, et. al, 1987; Yamamoto, et. al, 1988). However, it had not been clear when and in what posture the maximum pulling force is obtained. Therefore, the purpose of this study was to investigate the pulling force in the indoor tug of war, based on the change of the tugger 's posture, using the computer simulation, and considering the characteristics of human body such as body height, body weight, and holding height.

METHODS: The procedure of modeling and simulation in this study was constructed as follows (1) Modeling, (2) Data Input, (3) Validity of modeling, (4) Simulation, (5) Data output.
(1) Modeling: The model of human body was a 5-segmented (head including neck, trunk, upper limb, thigh, and shank including feet) rigid multibody two-dimensional (2-D) system (Figure 1.). The upper limb was fixed to the trunk. In order to change the posture of the model, 3 joints (ankle, knee, and waist) were put to the model as diarthrosis.
The center of gravity (CG) of each segment and synthesis center of gravity (SCG) were determined as shown in Table 1. The numeric value of CG was expressed as percentage of total segment length as measured from proximal end. The numeric value of SCG was expressed as percentage of the head age of each segment of C

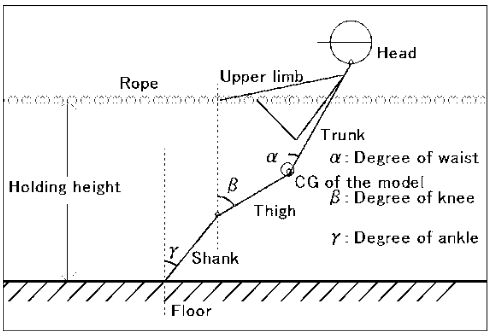

Figure 1 - The simulation model for tug of war.

Table 1 The Center of Gravity (CG) and Synthesis Center of Gravity (SCG) Value

Segment	Center of gravity (CG)
Trunk + neck + head	65
Thigh	42
Shank	41
-	Synthesis center of gravity (SCG)
Trunk+neck+head+:Lower limb	38
Trunk+neck+head+lower+limb :Upper limb	10

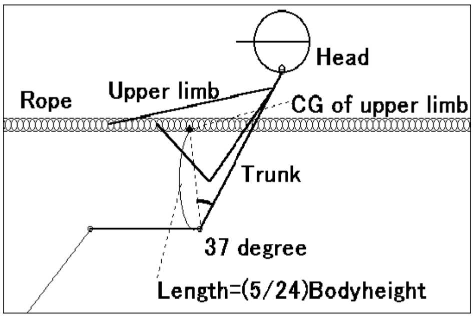

Figure 2 - The model of the upper limb.

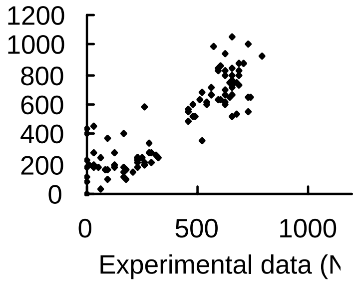

Figure 3 - The relationship between the experimental data and simulation data.

The model of the upper limb was shown in Figure 2. The elbow of one of the arms holding the tug was kept at the angle of 90 degrees, and CG of the upper limb was, trunk axis being at 0 degrees, located at 37 degrees counterclockwise, which was at a distance 5/24 body height from the waist. It was hypothesized that the armpits were at the place of 2/3 length of the trunk from the waist, and that the tug was carried under the model's upper limb.

(2) Data input: A 21-year-old, healthy and active college student (height: 1.64m; weight: 59kg) was recruited as a subject to verify the model. At the experiment, the angles of ankle, knee, and waist of the subject pulling the tug were measured with electrogoniometers originally made, and, via the variable resistor also originally made, were recorded on the oscillograph (RECTI-HORIZ-8K, SAN-EI INSTRUMENT CO., Ltd..). The pulling force of the subject pulling the tug was measured with the load cell (TCLP-200KA, Tokkyo Sokki Kenkyujo Co., Ltd.) via strain amplifier (6M46, SAN-EI INSTRUMENT CO., Ltd..) and strain gauge (5370, SAN-EI INSTRUMENT CO., Ltd..), and was recorded on the oscillograph. A tug used official games of tug of war was cut for this study. Putting on a pair of shoes (107-tug of war, ASCICS Co., Ltd) used exclusively for tug of war, the subject pulled the tug, doing his best trying to fix it at the height of 0.50m, with voluntary maximum pulling force at 4 trials (during 16 sec., 18 sec., 31 sec., and 32 sec.). Enough time was taken to have the subject rest between each trial. After the pull of tug, the data recorded on the oscillograph were input to the computer (FMV-DESCPOWER M/40L, Fujitsu Corp.).

(3) Validity of modeling: Figure 3 shows the relationship between the experimental data and simulation data of pulling force. The simulation data were calculated according to the pulling force estimated by the posture of the tugger, after inputting the experimental data (degree of ankle, knee, and waist, body height and weight) to the model, hypothesizing that the holding height was 0.50m, which was the same condition as that of the experiment. The coefficient of correlation was 0.879 (n=97, p<0.01). The relationship between the experimental data and the simulation data was so close, so it revealed that the model had validity.

(4) Simulation: The computer Basic Language (Microsoft Visual Basic 6.0, Microsoft Corp.) was used to develop the simulation program. Pulling force and 3 joint degrees as objective functions were computed by myocybernetic optimization, that is, in accordance with the changes of the tugger 's posture, considering the characteristics of human body such as height and weight. The simulation program was shown in Formula (A)

$$\{\alpha = 0,...60, \quad \beta = \alpha, \alpha+1, \alpha+2,...\rho-\alpha, \quad ? = \beta, \beta+1, \beta+2,...-\rho+\beta$$

$$f(?_d) = (\alpha, \beta, ?), \quad d = 1,2,3,...60e60e60$$

$$f(?_1) = (0,0,0), \quad f(?_2) = (0,0,1), \quad f(?_3) = (0,0,2),,, f(?_{60e60e60}) = (60, \rho-\alpha, -\rho+\beta) \qquad \text{(A)}$$

$$m_i(\vec{x_e}, \vec{y_e}) = g(f(?_e)); \quad e = 1,2,3; \quad M(\vec{x_f}, \vec{y_f}) = \sum_{j=1}^{3} m_j$$

$$\sum_V V(\vec{x_k}, \vec{y_k}) = 0; \ V = M, P, G; P: pulling\ force = p(\vec{x_k}, \vec{y_k}); \ G: Grand\ reaction\ force = G(\vec{x_k}, \vec{y_k})$$

Then, the loop system shown in Formula (B) was used.

$$\begin{aligned}
&pulling\ force = (PF); \quad (PF)_1 = p(\vec{x}_k, \vec{y}_k), \mathrm{e} = 0\\
&(PF)_{\max} = (PF)_1\\
&compare\ (PF)_{\max}\ and\ (\mathrm{PF})_{\mathrm{e}}\\
&\quad if\ (PF)_{\max} \geq (PF)_{\mathrm{e}}\ then\ (PF)_{\max} = (PF)_{\max}\ next\ (PF)_e\\
&\quad if\ (PF)_{\max} \leq (PF)_{\mathrm{e}}\ then\ (PF)_{\max} = (PF)_{\mathrm{e}}\ next\ (PF)_e\\
&(PF) = (PF)_{\max}
\end{aligned} \qquad \text{(B)}$$

RESULTS: The height being 1.70m and weight 70kg as the parameters of the model, maximum pulling force was derived, with holding height set per 0.02m between 0.40m and 1.20m. Simultaneously, the degrees of 3 joint angles were derived. Figure 4 shows the relationship between holding height and the degree of joint (ankle, knee, and waist) angle.
Figure 5 shows the relationship between holding height and pulling force. Coefficient of correlation of the relationship was –0.975 (n=40, p<0.01). There was high negative correlation of these two variables.
Figure 6 shows the relationship between body inclination and pulling force. Coefficient of correlation of the relationship was –0.961 (n=40, p<0.01). There was high negative correlation of these variables.

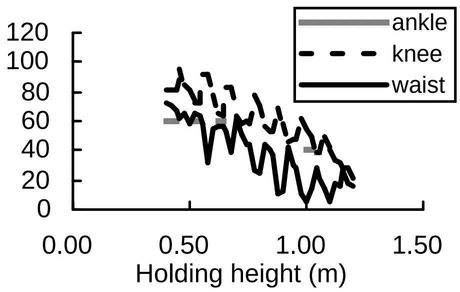

Figure 4 - The relationship between joint degrees of ankle, knee, and waist and holding height.

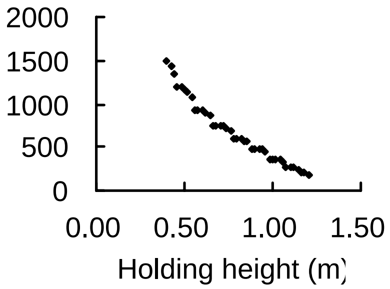

Figure 5 - The relationship between holding height and pulling force by simulation.

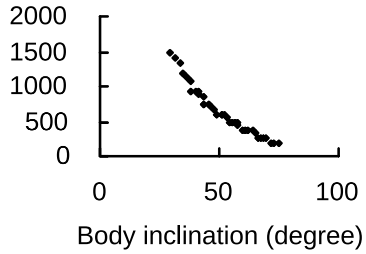

Figure 6 - The relationship between body inclination and pulling force.

DISCUSSION: In tug of war, it is important to consider the posture of pulling the tug to derive maximum pulling force as shown in Figure 4. It was inevitable that the degree of each joint was simultaneous with other joint to derive the maximum pulling force; the angles of ankle and waist were simultaneous as positive relation. The angle of knee was simultaneous as negative relation with other angles of joints (ankle and waist). The result of high relationship between holding height and pulling force agreed with previous studies (Chaffin, et al., 1983; Tanaka, 1993; Yamamoto, et al., 1991). It was observed that the lower the holding height was, the larger

the pulling force was (Figure 5.). The result of high correlation between body inclination and pulling force agreed with that of previous studies (Tanaka, 1993; Yamamoto, et al., 1995; Yamamoto, et al., 1991). David (David, et al., 1992) reported that pulling force was changed by posture, and it could be said that his theory was applied for tug of war in this study. Also, this study endorsed lateral studies such as Tanaka's (Tanaka, 1993) and Kroemer 's (Kroemer, 1974); Tanaka reported that the ideal posture in tug of war was limited to the ones of body inclination of 35-40 degrees, and Kroemer reported out the relationship between body inclination and pulling force. On the relationship between body inclination and pulling force, Yamamoto (Yamamoto, et al., 1995) reported that pulling force was increased by 1.4kg as the degree of body inclination increased by 1 degree. In this study, a linear regression equation of the relationship between body inclination and pulling force was formed as follows:
$Y=210.5 - 2.778X$ Where: Y was pulling force as dependent variable. X was body inclination as independent variable. It showed that pulling force was increased about 2.8kg as the degree of body inclination increased by 1 degree. This result did not agree with that of lateral study (Yamamoto, et al., 1995). The reason for this was considered to be the following; pulling force was measured at the best condition of pulling in this study, but if pulling force had been measured on various conditions, the result of pulling force would have been significantly different from the one of this study.

CONCLUSION: The purpose of this study was to investigate pulling force in the indoor tug of war, in accordance with the changes of the tugger 's posture, using the computer simulation, and considering the characteristics of human body such as height, weight, and holding height. The main aim of this study was achieved, and the results of this study could be summarized as the following 1 to 3.

1. Angle of ankle, knee, and waist were simultaneous to drive maximum pulling force.
2. The highly negative relation was existed between holding height and puling force.
3. The highly negative relation was existed between body inclination and pulling force.

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