DYNAMICAL PRINCIPLE OF LIFTING ACTION
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The manual lifting is a prevalent action during daily life and professional work. So low-back pain is common among these humans. Many experts make researches on this subject in various fields with experimental method. In this paper our research and analysis based on classical dynamic method. We simulated the lifting movement in the dynamic multi-segment model and defined θ (the angle between leg and ground) as generalized coordinate. Hence the equations of multi-body system were established. Through solving these equations, the angular velocity and angular accelerate of hip angle \( \dot{\theta} \), \( \ddot{\theta} \) and internal forces and moment of hip \( N_x \), \( N_y \), \( M \) were obtained. Especially, analytical solution of \( \ddot{\theta} \) was be obtained, it is convenient to further research internal mechanics of lifting. Based on above analysis, the conclusions show that main influence of \( N_x \), \( N_y \), \( M \) is the change of angular acceleration \( \ddot{\theta} \). The key factor to avoid injure is control the type of smooth lifting.

KEY WORDS: dynamic model, lifting, multi-segment

INTRODUCTION: The lifting is an action during daily life, especially to some professional worker. The action often makes injury at low back pain of them. A lot of researchers pay great attention to the relationship between human healths and injury of professional worker. Some experts of foreign countries, research on this subject in the filed of medicine, physiology, psychophysics and biomechanics. Most biomechanical researchers of our country concentrate on technical analysis for athletics. The subjects of research related to the human health are rather rare. Especially, there are a few articles about dynamic analysis on ergonomic. In this paper we will analysis mechanical principle of lifting action by using the method of classical dynamic and multi-body model. Muscular mechanical energy expenditure in manual materials handing and dynamic factors during asymmetrical lifting were be researched (Gagnon 1991, 1992, 1996) Dolan (Dolan et. al,1994) researched bending and compressive stresses acting on the lumbar spine during lifting. The method of their researches is main experimental measuring combined with statistics and numerical computing to make some suggestions for practical problems. In China some scholar (Lei Ling 2001, Zhu Liping 1999) did analysis and research on ergonomic and biomechanics of lifting respectively.

DYNAMIC MODEL AND CALCULATIONS:
The injury at low-back often happens during lifting. It is corresponding conclusion among these researchers. But they hold different analysis and views for explaining main reason to lead to injure. The type of lifting, heavy load and faster speed of lifting are three important reasons of injure. In this paper we emphasize mechanical principle and internal regulation of movement and try to obtain appropriate mechanical explanation about above problems. For convenience of analysis and calculation we suppose that the lifting action is bake typical lifting. The model included two segments with a load concentrated mass. These segments were: \( B_1 \)—a load, \( B_2 \)—head and trunk, \( B_3 \)—legs and feet. The segment was considered as a rigid body (Figure 1). The
link point between two rigid bodies could be simulated as a joint. We defined that the masses of $B_1, B_2, B_3$ are $m_1, m_2, m_3$ respectively. The moment of inertia of $B_2, B_3$ around their mass centers are $J_2, J_3$. The position of mass centers of $B_1, B_2, B_3$ are $(x_1, y_1), (x_2, y_2), (x_3, y_3)$ respectively. The position of joint between $B_2$ and $B_3$ is $O_1$. According to the property of lifting we assumed simulated model moves in planer coordinate system $O-xy$. Origin of coordinate $O$ is located at the center of foot. $\vec{r}_2, \vec{r}_3$ are the vectors from $O$ to centres of $B_2$ respectively. $\vec{r}_2, \vec{r}_3$ are the vectors from $O$ to centres of $B_2$ respectively. $\vec{r}_2$ is a vector from $O$ to centre of $B_2$, $\vec{r}_3$ is a vector from $O$ to $O_1$.

Consideration that $B_1$ rise vertically during lifting, we can assume $x_1=b$ (constant). $f, N$ respectively are horizontal and vertical constrained forces from ground. Then we can derive the equations of the movement based on theoretical dynamics

\begin{align}
\begin{align}
m_1\ddot{x}_1 + m_2\ddot{x}_2 + m_3\ddot{x}_3 &= f & \text{(1) a)} \\
m_1\ddot{y}_1 + m_2\ddot{y}_2 + m_3\ddot{y}_3 &= N - (m_1 + m_2 + m_3)g & \text{(1) b)} \\
J_2\dddot{\theta} + J_3\dddot{\theta} - m_2 \frac{d}{dt}(\vec{r}_2 \times \ddot{\vec{r}}_2) + m_3 \frac{d}{dt}(\vec{r}_3 \times \ddot{\vec{r}}_3) + m_2y_1x_1 &= -(m_1x_1 + m_2x_2 + m_3x_3)g & \text{(1) c)}
\end{align}
\end{align}

Where the angles $\alpha, \beta$ are from x axis to trunk and leg as general coordination respectively.

Then, we can write:

\begin{align}
\begin{align}
x_1 &= 0 & \dot{x}_1 &= \dot{x}_2 = 0 & y_1 &= e\hat{h} & \dot{y}_1 &= \hat{e}\hat{h} & (e \text{ is unit length}) \\
x_2 &= l \cos \theta + r_2 \cos \alpha & \dot{x}_2 &= l \dot{\theta} \cos \theta + r_2 \dot{\alpha} \cos \alpha \\
\ddot{x}_2 &= -l \dot{\theta} \sin \theta - r_2 \dot{\alpha} \sin \alpha \\
\dddot{x}_2 &= -l \dddot{\theta} \cos \theta - r_2 \dddot{\alpha} \cos \alpha \sin \alpha - r_2 \dot{\alpha}^2 \sin \alpha \\
\dddot{x}_3 &= -r_2 \dot{\alpha} \sin \theta \\
\dddot{x}_3 &= -r_2 \dddot{\alpha} \sin \theta - r_2 \dot{\alpha}^2 \cos \theta \\
\dddot{y}_3 &= r_2 \dot{\alpha} \cos \theta \\
\dddot{y}_3 &= r_2 \dddot{\alpha} \cos \theta - r_2 \dot{\alpha}^2 \sin \theta \\
\frac{d}{dt}(\vec{r}_2 \times \ddot{\vec{r}}_2) &= -\dddot{x}_2 y_2 + \dddot{y}_2 x_2 \\
\frac{d}{dt}(\vec{r}_3 \times \ddot{\vec{r}}_3) &= -\dddot{x}_3 y_3 + \dddot{y}_3 x_3 & \text{(2)}
\end{align}
\end{align}

Considering the relationship among $\theta, \alpha, \alpha$ during practical lifting, we suppose: There exist the differential constraints: $\dot{\theta} = -k \dot{\alpha} = -p \dot{\theta}$. If the boundary is $\theta = 120^\circ - 90^\circ$.

Substituting (2), into (1) and simplifying, we obtained:

\begin{align}
\begin{align}
f &= [2m_2r_2 \cos 2\theta - (m_1l + m_2r_2) \sin \theta] \dddot{\theta} - [4m_2r_2 \sin 2\theta + (m_1l + m_2r_2) \cos \theta] \dot{\theta}^2 & \text{(3)} \\
N &= \left[ \frac{24}{5\pi} m_2 r_2 \sin 2\theta + (m_1l + m_2r_2) \cos \theta \right] \dddot{\theta} + \left[ 4m_2r_2 \cos 2\theta - (m_1l + m_2r_2) \sin \theta \right] \dot{\theta}^2 + (m_1 + m_2 + m_3)g & \text{(4)} \\
[\mathcal{H}_1(\theta) \dddot{\theta} + \mathcal{H}_2(\theta) \dot{\theta}^2] &= \mathcal{H}_3(\theta) & \text{(5)}
\end{align}
\end{align}

Where

\begin{align}
\mathcal{H}_1(\theta) &= -2 J_2 + J_3 + m_1 l^2 + m_2 r_2^2 - 2 m_1 r_2 l \cos(\alpha - \theta) + m_2 b \frac{24}{5\pi} \\
\mathcal{H}_2(\theta) &= 3 m_2 r_2 l \sin(\theta - \alpha) \\
\mathcal{H}_3(\theta) &= -[m_1 b + m_2 (l \cos \theta + r_2 \cos \alpha) + m_3 r_3 \cos \theta] g
\end{align}

Substituting it into (9) we can obtain first order differential equation

\begin{align}
\frac{1}{2} \frac{d^2 y}{d\theta^2} [\mathcal{H}_1(\theta) + \mathcal{H}_2(\theta)] y = \mathcal{H}_3(\theta) & \text{(6)}
\end{align}

Solving (10), we obtained analytic function.
Figure 2 The model of separated body.

RESULTS AND DISCUSSION: After obtaining these solutions we can get some results as follows: We obtained maximum peak values of some functions in above curve and calculation.

(1) $\dot{\beta}=168^\circ$/sec, $\ddot{\beta}=426^\circ$/sec$^2$, $N_x=42$ N, $N_y=832$ N, $M=351$ Nm
These data are smaller than the data from the references (Lei Ling, 2000; Zhu Liping, 1998). Because we assumed the process of lifting is smooth. Therefore we can think the theoretical model in this paper is an optimum type of lifting and a good supplement of experiments.

(2) By 8 equations it shows that the increment of the load at the hip has positive correlation with angular acceleration \( \dot{\theta} \) and negative correlation with angular velocity \( \dot{\theta} \). The result indicates increasing angular acceleration is the essential reason of the increment of the load at the hip.

(3) According to the results of calculation the knee typical lifting is better than the back typical lifting in quantities analysis. Because the essential difference between two typical lifting is that vector \( \vec{r}_3\vec{r}_3\) of knee-type is smaller than back-type. Hence the angular acceleration \( \dot{\theta} \) will decrease in the knee-type. Through calculation of above method. So we can think that the knee typical lifting is better one in theory.

(4) Comparing the parametric curves of this paper with other curves from experiments, the later display singular point in the curves it is caused by movement when the lifting suddenly accelerate. The curves are smooth and differentiable in this paper. Besides, the results of analytic function are obtained in this paper. It is more valuable than numerical results for further research of mechanical principle.

CONCLUSION: Based on some analyses above, we can conclude as follows: First, the research of lifting in dynamic model is necessary and valuable. Second, it is helpful to explore mechanical principle of movement and it is also a good supplement to the experimental method. Third, it proves that the key factor which influences the loads at the hip is the angular acceleration \( \beta \) (hip angle) in lifting. Finally, the better way to avoid injury is smooth type of lifting.

REFERENCES: