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The deadlift form analysis system using Microsoft Kinect

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Abstract

Weight training leads to muscle injury for inexperience exercise. The deadlift form is one of high risk posture of weight training. Therefore, the prevention of incorrect deadlift form needs an expert trainer. Some people are not be able to effort the private trainer cost. This research presents the deadlift form analysis system using Microsoft Kinect. Microsoft Kinect can be applied to detect the deadlift form with its full body motion capability the Chaffin's biomechanical modeling. The Chaffin's model is used to calculate two forces, compression force and shear force, on lumbosacral disc (L5/S1). Results of this research can help the people to practice the corrected deadlift form and reducing injuries on lumbosacral disc (L5/S1) using Microsoft Kinect. The accuracy of this system is 80.9%.

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Keywords: Microsoft Kinect; weight training; deadlift; Chaffin's model

1. Introduction

The weight training is popular and one of exercise[1]. Kerr at al[2] found 90.4% of the weight training injuries cause by free weight. The deadlift form is one of free weight form. The incorrect deadlift form causes more compression force (F_c) and shear force (F_s) on lumbosacral disc (L5/S1) or herniated discs[3].

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The proposed system can detect the human posture who dose deadlift in real time to prevent the incorrect posture and to avoid the injuries of the lumbosacral disc (L5/S1). The system calculates the compression and the shear force on the lumbosacral disc using the Chaffin's model.

2. Research hypothesis

2.1. Injuries of deadlift

Tony Leyland[3] studies a biomechanical model of the deadlift and considers the compression force (F_c) and shear force (F_s) acting on the lumbosacral disc (L5/S1). The line of action of the erector musculature must pulls on the spine with hundreds of pound of force to lift common loads and creates compression between them. If the incorrect deadlift form is used the erector musculature cannot pull on the spine. The risk of lumbar spinal injuries are increase.

To reduce the risk, the deadlift is modeled using a commercially available biomechanical computer modeling program, 4DWATBAK[3] . The 4DWATBAK uses height, weight, sex and weight of load of participant as parameters. The model calculates the compression and the shear force cause by the corrected deadlift and the incorrected deadlift. Experimental results show that the incorrected deadlift generates more compression force and shear force at the lumbosacral disc (L5/S1) than the corrected deadlift. A suggested safe cutoff point at 3,433 Newtons was established by NIOSH (National Institute for Occupational Safety and Health) in 1981[5]. The University of Waterloo ergonomic research group has suggested 500 Newtons as a safe limit and 1,000 Newtons as a maximal permissible limit.

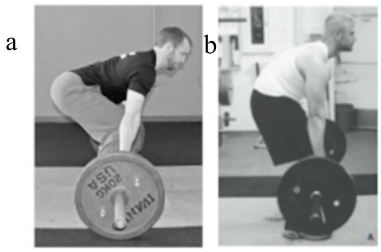

Fig. 1. (a) The correct deadlift; (b) The incorrect deadlift.

2.2. *Chaffin's model*

The Chaffin's model[5] is used for calculating compression force and shear force acts lumbosacral disc (L5/S1) as shown in Fig. 2.

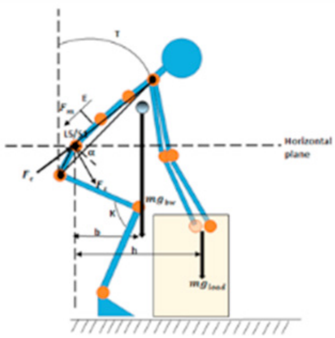

Fig. 2. The Chaffin's model.

3. Methodology

3.1. Calculation of the posture angles

This research uses Pythagorean theorem and dot product of 3 dimensional vector for calculating 4 variables in the Chaffin's model which are b, h, T and K shown in Fig. 3.

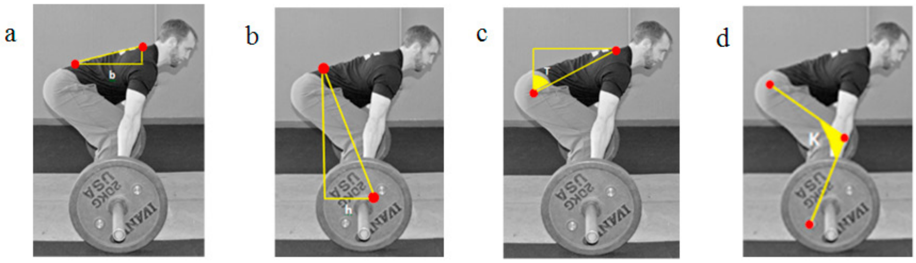

Fig. 3. (a) Definition of b value; (b) Definition of h value; (c) Definition of T angle; (d) Definition of K angle.

3.1.1. b value

b is a distance from upper trunk to the lumbosacral disc (L5/S1).

$$b = \sqrt{(shoulderCenter.x - spine.x)^2 + (shoulderCenter.z - spine.z)^2} \tag{1}$$

From (1), the $shoulderCenter.x$ and the $shoulderCenter.z$ are the distance from Microsoft Kinect to the shouder center in X and Z coordinate respectively. The $spine.x$ and the $spine.z$ are the distance from Microsoft Kinect to the spine in X and Z coordinate respectively.

3.1.2. h value

h value is a distance from the center of mass to the lumbosacral disc (L5/S1).

$$h = \sqrt{(handRight.x - spine.x)^2 + (handRight.z - spine.z)^2} \tag{2}$$

From (2), the $handRight.x$ and $handRight.z$ are the distance from Microsoft Kinect to the right hand in X and Z coordinate respectively. The definition of the $spine.x$ and the $spine.z$ are the same as b value calculation.

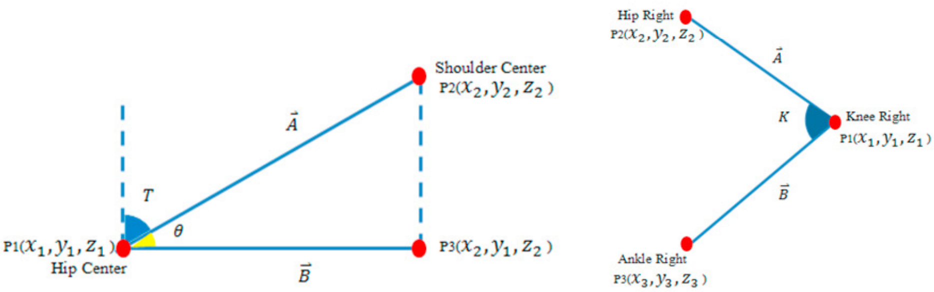

Fig. 4. (a) Definition of T angle; (b) Definition of K angle.

3.1.3. T angle

T is the angle of the upper trunk and vertical axis as shown in Fig. 4 (a).

$$T = 90^o - \theta = 90^\circ - arccos\left\{\frac{\vec{U}\cdot\vec{V}}{|\vec{U}|\,|\vec{V}|}\right\}$$

$$= 90^\circ - arccos\left\{\frac{(x_2-x_1)^2+(z_2-z_1)^2}{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2}\sqrt{(x_2-x_1)^2+(z_2-z_1)^2}}\right\} \quad (3)$$

From Fig. 4(a), $\vec{\boldsymbol{U}}$ is a three dimensional vector created by the points of the hip center (P1) and the shoulder center (P2). The point P3 is the projection of P2 in the plane $Y = y_1$. The hip center and P3 are used to create $\vec{\boldsymbol{V}}$. The dot product method is applied to find the angle θ between $\vec{\boldsymbol{U}}$ and $\vec{\boldsymbol{V}}$ as shown in (3). Therefore, the definition of T implies that $T = 90^\circ - \theta$.

3.1.4. K angle

K is the angle of knee as shown in Fig. 4 (b).

$$K = arccos\left\{\frac{(x_2-x_1)(x_3-x_1)+(y_2-y_1)(y_3-y_1)+(z_2-z_1)(z_3-z_1)}{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2}\sqrt{(x_3-x_1)^2+(y_3-y_1)^2+(z_3-z_1)^2}}\right\} \quad (4)$$

Let P1, P2 and P3 be 3 points of the right knee, the right hip and the right ankle respectively. Equation (4) calculates the angle between 2 vectors as same as (3).

3.2. Calculation of the compression force and the shear force on the lumbosacral disc (L5/S1)

From Fig. 2, the Chaffin's model were derived into two equations for calculating the compression force and the shear force acting on the lumbosacral disc (L5/S1). The compression force (F_c) and the shear force can be calculated from (5) and (6) respectively.

$$F_c = (mg_{bw})cos\alpha + (mg_{load})cos\alpha + F_m \quad (5)$$

$$F_s = (mg_{bw})sin\alpha + (mg_{load})sin\alpha \quad (6)$$

From (5), F_m is the force of muscle for holding the body in the deadlift form calculated by (7) and E is a constant defined as *5*[7]

$$F_m = \frac{(b)(mg_{bw})+(h)(mg_{load})}{E} \quad (7)$$

From the biomechanical model in Fig. 2, rotation of pelvis is considered because of changing of arch and area of disc . Chaffin used the angle between body and vertical (T) and knee angle (K) for integrating with the slope of sacrum (S1). Sacrum is the base to be used to hold lumbosacral disc (L5/S1). From Fig. 2, suppose α be an angle between the top of sacrum (S1) and horizontal calculated by (8).

$$\alpha = 40^o - 17.5 - 0.12T + 0.23K + 0.0012TK + 0.005T^2 - 0.00075K^2 \quad (8)$$

From (5) and (6), α is an angle of sacral cutting plane from the horizontal calculated from (8). From (7), mg_{bw} is a weight of body parts which are above lumbosacral disc (L5/S1). This research uses mg_{bw} as 60.06% of the whole body weight[6]. mg_{load} is a weight of lifting object .Equation (8) shows an empirical relationship between T and K angle .

3.3. Experiment for creating the criteria to detect the correct deadlift form and the incorrect deadlift form

This research collects data of 3 trainers for creating the normal distribution of K angles for each $T \in \{15°,20°,25°,...,40°\}$. Each trainer will do the deadlift in the corrected form 30 times and the postures are shown in Fig. 5.

Fig. 5 .Three trainer deadlift in the correct deadlift for 30 times.

The K angle distribution of 3 trainers will be used to verify the corrected deadlift form and the incorrected deadlift form of all participants. Mean value and standard deviation of the K angle distribution of 3 trainers were calculated for each $T \in \{15°,20°,25°,...,40°\}$ .Mean value and standard deviation will be used to normalize data using Z-Score which will be discussed in section 3.4.

The 25 participants and mg_{load} 1 kg were used for testing the correct deadlift 5 times and the incorrect deadlift 5 times as shown in Fig. 6. All participants are video-recorded for cross checking the postures. The environmental of this experiment has many factor .The light intensity is set between 30 to 45 LUX .The distance from Microsoft Kinect to a participant is set as 287 cm with the angle as 30^{o} from horizontal. The height from Microsoft Kinect to the floor is equal to 82 cm. The angles of Microsoft Kinect and a participant is equal to 45^{o} .The height of barbell to the floor is equal to 26 cm.

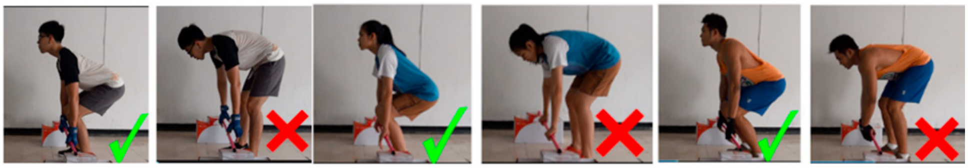

Fig. 6. Example of participants in the corrected and incorrected deadlift from

3.4. Data normalization

Since a K angle of a participant must be compared with the K angle distribution of 3 trainers for every $T \in \{15°,20°,25°,...,40°\}$. This research wants to find the area of a participant's K angle in the K angle distribution of 3 trainers. Therefore, the normalization techniques are required because the K angle distribution of 3 trainers are not the same distribution. Z-score is a tool for normalizing the data. Mean value ($\bar{X}$) and standard deviation (SD) of 3 trainers are required to calculate Z-score and the standard normal distribution of K angle. For each the angle $T \in \{15°,20°,25°,...,40°\}$, the transformation of K angle of all participants to Z-score is defined by (9),

$$z = \frac{X-\bar{X}}{SD} \tag{9}$$

where

$\underline{X}$ = K angle for each $T \in \{15°,20°,25°,...,40°\}$

X = mean value for each trainer for each $T \in \{15°,20°,25°,...,40°\}$

SD = standard deviation for each trainer for each $T \in \{15°,20°,25°,...,40°\}$.

4. Results

As discussed in section 3.3, this research chooses T angle and K angle for creating the criteria to detect the corrected deadlift form because the relation of both angles satisfy the movement of deadlift as shown in Fig. 7.

a b

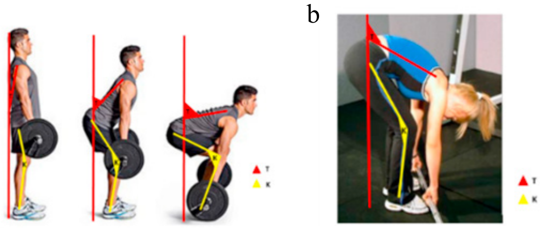

Fig. 7. (a) The relation of T and K angle of the correct deadlift; (b) Show T and K angle of the incorrected deadlift form.

From Fig. 7 (a), the characteristic of the corrected deadlift form and the incorrected deadlift form is that T angle is inversely variation to K angle but the rate of change of K angle in the corrected deadlift form is greater than the incorrected deadlift form.

The criteria of the corrected and incorrected deadlift form is the normalized K angle distribution of 3 trainers which are divided into 5 interval for each $T \in \{15°,20°,25°,...,40°\}$ as shown in Table 1.

Table 1. The interval of area1 to area5.

Z-Score	*Area*
$Z < -1.0$	1
$-1.0 \leq Z < -0.5$	2
$-0.5 \leq Z < 0.5$	3
$0.5 \leq Z < 1.0$	4
$Z \geq 1.0$	5

From Table 1, the name of 5 intervals are defined as *Area1*, *Area2*, *Area3*, *Area4* and *Area5* respectively. The value 0.5 is chosen as a step of standard deviation for each the normalized K angle distribution. The step of standard deviation need not equal to 0.5. This research chooses 0.5 because the characteristic of the correct and incorrect deadlift is difference clearly as this value.

The K angles of 25 participants for each $T \in \{15°,20°,25°,...,40°\}$ are normalized using mean and standard deviation of 3 trainers as discussed in section 3.4. Therefore, one participant has 3 Z-scores for each $T \in \{15°,20°,25°,...,40°\}$. The number of Z-score in *Area*1 to *Area5* of all participants are considered and the results are shown in Fig 8.

a b

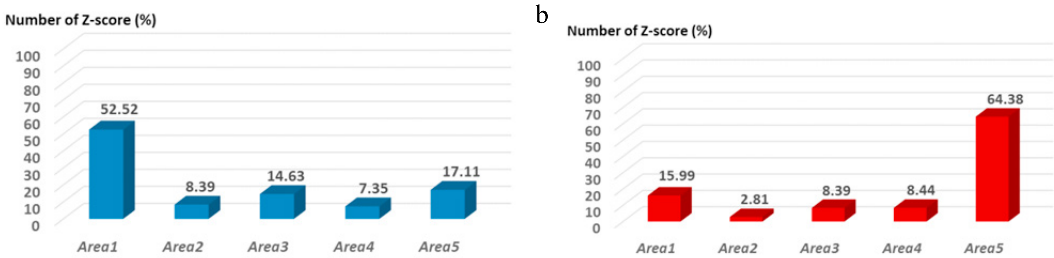

Fig. 8. (a) The percentage of Z-scores in Area1 to Area5 of 25 participants in the corrected deadlift form (b) The number of Z-score in Area1 to Area5 of all participants in the incorrected deadlift form

From Fig. 8, the corrected deadlift form has the highest percentage of Z-score at *Area1* because the knee bending helps the back straight of the object lifting .Therefore, 25 participants do the knee bending more than the knee angle of trainers for safety .*Area5* is the highest value in the incorrected deadlift form since the back bending helps the hand of participants move to the object faster than the back straight but the forces are dangerous on the lumbosacral disc (L5/S1).

Table 2. Percentage of total Z-Score of area1 to area5 and the weighted score is defined by rank of difference of area1 to area5

Area	*Corrected (%)*	*Incorrected (%)*	*Difference*	*Weighted score*
1	52.52	15.99	36.53	5
2	8.39	2.81	5.58	3
3	14.63	8.39	6.24	4
4	7.35	8.44	-1.09	2
5	17.11	64.38	-42.27	1

From Table 2, the weighted score is defined from the rank of the difference of percentage of total Z-score that fallen in *Area1* to *Area5* .Since one participant has 3 *Area* calculated from 3 trainers for each $T \in \{15°,20°,25°,...,40°\}$. Hence, the possible weighted score will lie in the interval [3, 15], *Pass* is defined by a participant has a weighted score at least 9 and the number of *T* angle greater than or equal 3. *NotPass* is defined by a participant has a score less than 9 and the number of *T* angle is less than 3 .The weighted score 9 is chosen for the *Pass* because of calculating from (10). Total of criteria in inequality (10) is 2 values which are *Pass* and *NotPass*.

$$Weighted\ score\ of\ Pass \geq \frac{Range}{Total\ criteria} + Minimum\ score \quad (10)$$

The accuracy of this system can measure by (11) and (12)

$$\%Acc_{corr} = \frac{1}{N_1}\sum_{i=1}^{N_1} Pass_i \times 100 \quad (11)$$

$$\%Acc_{incorr} = \frac{1}{N_2}\sum_{i=1}^{N_2} NotPass_i \times 100 \quad (12)$$

where N_1 and N_2 is the number of experiments.

$\%Acc_{corr}$ and $\%Acc_{incorr}$ are calculated from the proportion of the total number of *Pass* and *NotPass* respectively. The data of 25 participants are traced to calculate the accuracy of the criteria. the system can detect the corrected and the incorrected deadlift form where the accuracy are 77.14 % and 82.61% respectively.This criteria of the system is proved by testing with another 5 participants .All participants do the corrected deadlift 5 times and the incorrected deadlift 5 times .The results show that the system can detect the corrected and the incorrected deadlift form where the accuracy are 70.29 % and 88.00 %respectively .Therefore, the accuracy of this system is 80.9 % calculated by the summation of $\%Acc_{corr}$ of the corrected deadlift form and $\%Acc_{incorr}$ of the incorrected deadlift form and divided by the summation of N_1 and N_2. As discussed in section 3.2, this system can calculate the compress force (F_c) and the shear force (F_s) .From 25 participants, the average F_c and $F_s$of the corrected deadlift and the incorrected deadlift are shown in Fig. 9.

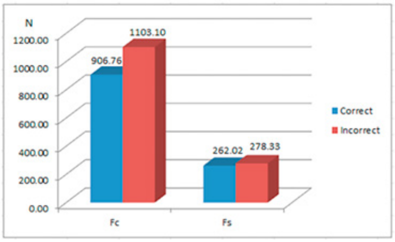

Fig. 9. The difference of forces of the corrected deadlift and the incorrected deadlift

From Fig. 9, the difference of F_s of the corrected and the incorrected deadlift form is not significant. As discussed in section 2.1, the F_s of Tony Leyland of the corrected and the incorrected deadlift form are 699 Newtons and 3,799 Newtons respectively . Tony Leyland gets more difference force than this research because the parameters of experiment are not the same as this system . Toney Leyland uses mg_{load} =1,360 Newtons and mg_{bw} = 546 Newtons but this research uses mg_{load} = 10 Newtons and mg_{bw} lies between 300– 613 Newtons . Tony Leyland uses the commercial software called *4DWATBAK* . The *4DWATBAK* is a biomechanical software which has more parameters for calculating the forces . But this research uses the Chaffin's model as explained in section 3.2.

From (6) and (8), the Chaffin's model shows that F_s is a function of α and α is a function of T and K angle . Therefore, F_s is a function of T and K angle. To compare with Tony Leyland, if mg_{load} and mg_{bw} is set the same as Tony Leyland condition, then the maximum F_s of this research is 1,906 Newtons as T $=90^o$ and K $=180^o$ and the minimum F_s is 1,214 Newtons as T $=0^o$ and K $=180^o$. The results of the comparison with Tony Leyland implies that the Chaffin's model can calculate the compression and the shear force but the forces cannot be compared with the commercial software *4DWATBAK* because of the limitation of The Chaffin's model and the parameters. However, this research uses the divided areas of the normalized K angle distribution and the weighted scoring to prove that the proposed system be able to detect the corrected and the incorrected deadlift form.

5. Conclusion

The deadlift is an exercise posture which has more risk of back injuries. This research presents the deadlift form analysis system using Microsoft Kinect. Microsoft Kinect can be applied to detect the deadlift form with its full body motion capture and the Chaffin biomechanical modeling. The Chaffin's model is a model used to calculate the compression force and the shear force on lumbosacral disc (L5/S1).

This research collects data of 3 trainers for creating the normal distribution of K angles for each $T \in \{15°,20°,25°,...,40°\}$. Each trainer will do the deadlift in the corrected form 30 times . The K angle distribution is used for 25 participants to create the criteria of the system . The criteria is defined by score defined from the score ranking base on the percentile of the Z-score which ranked into 5 areas. These 5 areas are defined by K angles distribution of the trainers.

The experiment shows that Microsoft Kinect be able to classify the corrected and the incorrected deadlift form . The accuracy of this system is 80.9%. This research can be improved the precision of angle calculation using Microsoft Kinect V2 which has better resolution for the traditional camera and the depth sensor than Microsoft Kinect V1[8] . This system calculates the compression and the shear force using the Chaffin's model . The results show that the compression and the shear force of the corrected deadlift form .

This research can be used to develop the application for preventing the incorrected deadlift form . The application can alert in the real-time if the posture is wrong . Microsoft Kinect may be used to apply with the other postures since the exercise has many high risk posture caused from weight training such as squat posture and bench press posture etc.

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