Effect of body mass index and chair height on the torque developed at the knee joint during back-to-sit and sit-to-stand movements

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Abstract: Back-to-sit (BTS) and sit-to-stand (STS) are one among many vital functions of knee joint of human body. While designing bipedal robots, the knee joint should have the capacity to replicate the characteristics, such as that of human beings, especially the torque. The effect of weight and length as well as sitting chair height and speed of movement during BTS and STS has to be studied to limit the weight and height of robots or exoskeleton. Here we have used a camera and motion analysis software to acquire the data and studied the effect and interaction of body mass index and chair height on knee torque at various sitting speeds using two-way analysis of variance.

Keywords: BMI; BTS; chair height; STS; torque.


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K.S. Sivanandan received the BTech degree in Electrical Engineering from Nair Society Service College of Engineering, India, in 1977, MTech in Control Systems from National Institute of Technology Calicut, India, in 1979 and the PhD degree in Electrical Engineering in 2000 from the Indian Institute of Technology, Roorkee, India. Currently, he is a Professor at the Department of Electrical Engineering at the National Institute of Technology Calicut, India. His research involves Instrumentation and Control Systems, Modeling and Analysis and Bio-mechanics.

1 Introduction

In human daily routine life, back-to-sit (BTS) and sit-to-stand (STS) movements are unavoidable. These movements are possible only if a number of degrees of freedom of musculoskeletal system are coordinated both at joints and at muscles (Yamasaki et al., 2014; Demura et al., 2003). Elderly people and middle aged people have to take a greater effort to achieve an STS movement with leg muscle functional lowering a balancing function (Alexander et al., 1991). This difficulty during STS restricts them from performing many essential activities (Jones et al., 1999) such as exercising and entertainments, which in fact leads to other health issues.

Difficulty in performing STS is not only the issue in rehabilitation of elderly, but also a greater consideration is given for the strength required for the leg to withstand the ground reaction force (Fleming et al., 1991; Lindemann et al., 2003; Nakatani et al., 2002). While performing an STS movement, the body tries to stabilise quickly, which requires a forcible knocking. The effect of this forcible knocking is transferred through muscles or lower limb to the floor and is reflected in a floor reaction force–time curve (Jones et al., 1999). Moreover, the body’s centre of gravity shifts its position through muscles and many joints, when performing a STS movement. When STS is performing with a different chair height, degree of engagement of joints and muscles for performing this action also alters (Vander Linden et al., 1994; Doorenbosch et al., 1994). Thus, chair height has a significant role in accomplishing the STS movement and imposing stress in muscles (Janssen et al., 2002). Torque at knee joint is approximately 1.3 times higher than the hip torque during STS movement (Winter, 2009). Moments at knee is reduced up to 60% while using chairs with greater heights, while hip moment requirement slashes up to 50%. Moreover, chair height lowering demands for a higher momentum generation or to change the position of the feet in order to reduce the required moment at knee and
Effect of body mass index and chair height

thigh joints. Armrest usage also lowers the torque required at the hip joint by 50%, without affecting the normal degree of motion of joints (Seven et al., 2008). Back loading is another factor that influences the torque at knee and ankle joints. Power and moment at ankle and knee joints are increased as a result of back loading, while it does not affect hip kinetics (Dubost et al., 2005).

Thus, the torque at joints required to keep the body back in position during its centre of gravity change, when performing BTS and STS on a varying chair height, will be of great importance. In addition to this, when the subject performs STS and BTS with a certain velocity, it adds an additional dynamic force requirement that is to be developed by the knee joint and hence burdens the joint.

Effect of thigh length on floor reaction force during STS movement is studied by Jones et al. (1999). The highest peak of trunk flexion is in the middle period of STS (Manckoundia et al., 2006). Velocity profiles during STS and BTS are almost same at their peaks in healthy as well as unhealthy subjects. Although velocities of both movements are approximately equal, the time duration is shorter during STS and longer for BTS (Manckoundia et al., 2006).

Here we include a factor, body mass index (BMI) that gives a ratio of body weight and height, to study its effect on a varying chair height during BTS and STS. Also, the chair height is varied in two height levels and STS and BTS movements are performed at two different speed levels, one at a moderate speed and other at a faster speed. Two CMOS cameras with 60 fps and KINOVEA motion analysis software are used for measuring the position, velocity and acceleration of the thigh joint. Factor analysis is conducted with the help of two-way ANOVA, to study the effect and interaction of BMI and chair height on torque developed at the knee joint. KINOVEA is a video analysis software dedicated for the sports kinematic analysis and ergonomics study whereas, analysis of variance (ANOVA) is a statistical method to study the significant effect of the factors and the interaction between these factors in a process that can influence a process. This study has the relevance in the field of biomechanics and robotics, to design a bipedal robot or an exoskeleton knee joint.

2 Method

2.1 Experimental setup

A video analysis of eight different subjects was made to study the torque required at knee joint during BTS and Stand-to-Sit conditions. The setup consists of a height adjustable chair, a rectangular plane of area 2 m², a 60 Fps Canon CMOS Camera. Rectangular plane is placed perpendicular to floor near the adjustable chair. The camera is adjusted to focus on to the perpendicular rectangular plane, which is facing the chair, with its focal length perpendicular to the surface area of the plane.

The chair has three levels of height adjustments. Maximum height is 50 cm, second level adjustment is 40 cm and third level is 38 cm. Eight male subjects with age between 25 and 40 are chosen to study the torque requirements at the knee during BTS and STS.

The chair is adjusted to first-level height. White markers are placed on the knee, hip and ankle joints of these subjects (Figure 1) to represent the rotation at these joints.
They are advised to sit initially from standing position (BTS) at a moderate speed and then to stand back (STS). BTS and STS are continued at a faster speed with the same level of chair height adjustment. This process is continued for other two levels of chair height for single subject. Eight subjects are subjected to this process and the video was recorded.

**Figure 1** BTS and STS trials of subjects on varying chair height (see online version for colours)

\[ \text{Note: BTS, back-to-sit; STS, sit-to-stand} \]

2.2 *Analysis using KINOVEA software*

This recorded video is uploaded into KINOVEA to get the kinematic variables, such as angular displacement, velocity and acceleration for the thigh with respect to below knee. Virtual pointer in the software is placed on the white joint markers in the video. While playing the video after pointing, the pointer trace the trajectory of this joint motion with respect to time and the displacement is measured in pixels, which are converted into meters during post processing and thus these kinematics variables are calculated.

All other anthropometric data are measured externally including weight, thigh length, knee length and height. BMI, which is the ratio of weight (W) in kilograms to square of the height (H) in meter is calculated from these data.

\[
\text{BMI} = \frac{W}{H^2}
\]  

(1)
3 Torque calculation

3.1 Weight proportions

Thigh weight is assumed to act at centre of mass of the thigh as in Figure 2. Whole upper body weight is assumed to act at the hip joints. Since the total weight of the upper body acts on the hips, half the weight of upper body is only acting on one hip. Trunk, the head, upper arms, fore arms and hands are considered as upper body parts. Those weights are calculated as the proportion of the total body weight (W) as in Table 1 (Seven et al., 2008).

Figure 2  Line diagram of thigh showing mass concentration of the upper body

Table 1  Weight proportion of human body parts

<table>
<thead>
<tr>
<th>Proportions</th>
<th>Thigh mass</th>
<th>Trunk weight</th>
<th>Head weight</th>
<th>Upper arm</th>
<th>Fore arm and hand</th>
<th>$\rho_{\text{thigh}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1 W</td>
<td>0.497 W</td>
<td>0.081 W</td>
<td>0.028 W</td>
<td>0.022 W</td>
<td>0.323 W</td>
</tr>
</tbody>
</table>

$\rho_{\text{thigh}}$, thigh density; W, total weight of the body

3.2 Moment of inertia

Moment of inertia of thigh mass with mass ($m_{\text{thigh}}$), length ($l$) and density ($\rho_{\text{thigh}}$) about the centre of gravity of thigh ($I_{\text{Cog}}$) is given by

$$I_{\text{Cog}} = m_{\text{thigh}} \times (\rho_{\text{thigh}} \times l)^2$$  \hspace{1cm} (2)

Moment of inertia about the knee joint ($I_{\text{Knee1}}$) due to thigh mass ($m_{\text{thigh}}$) is calculated using parallel axis theorem

$$I_{\text{Knee1}} = I_{\text{Cog}} + m_{\text{thigh}} \times \left( \frac{l}{2} \right)^2$$  \hspace{1cm} (3)
Moment of inertia about the knee joint \((I_{\text{Knee2}})\) due to the upper body weight \((m_{\text{upper}})\) acting at the end of thigh (hip joint) is given by

\[
I_{\text{Knee2}} = m_{\text{upper}} \times (l)^2
\]  
(4)

Total moment of inertia acting about the knee joint \((I_{\text{Knee}})\) is given by (3) + (4)

\[
I_{\text{Knee}} = \sum_{i=1}^{2} I_{\text{Knee}(i)}
\]  
(5)

where \(I_{\text{Cog}}\), moment of inertia of thigh about its centroidal axis; \(m_{\text{thigh}}\), mass of the thigh; \(l\), radius of gyration of knee joint; \(l\), length of thigh; \(m_{\text{upper}}\), mass of upper body.

3.3 Torque at Knee

Torque \((\tau)\) is calculated using Lagrangian formulation for 1 DOF.

\[
\tau = M(\theta)\dot{\theta} + H(\dot{\theta}, \theta)\ddot{\theta} + G(\theta)
\]  
(6)

\[
\tau = \left(\frac{m_{\text{thigh}} \times l^2}{4} + I_{\text{Knee}}\right)\ddot{\theta} + \frac{m_{\text{thigh}} g l \cos \theta}{2}
\]  
(7)

where \(M(\theta)\), mass inertia matrix; \(H(\dot{\theta}, \theta)\), coriolis and centrifugal component; \(G(\theta)\), gravitational term; \(\dot{\theta}, \ddot{\theta}\), thigh angular acceleration, thigh angular velocity; \(\theta\), angle of rotation; \(g\), acceleration due to gravity.

4 Two-way ANOVA analysis

Analysis of variance (ANOVA) is the statistical method that tests the truthiness of the null hypothesis and the alternate hypothesis. The null hypothesis states that means of all the population are equal and alternative hypothesis states at least one means is different. ANOVAs assess the importance of one or more factors by comparing the response variable means at the different factor levels. Two-way ANOVA test is conducted to study the effect of factors (variables) and its interaction on dependent variables of a process if the process is governed by at least two independent factors and each factor has at least two levels.

The two-way ANOVA test is basically conducted to identify the effect of the factors, BMI and chair height, on the torque developed at the knee joint for two different angular velocity. The variation in angular velocity is made when the subject perform BTS and STS in a faster and slower rates.

\[
Y_{ijk} = \mu + A_i + B_j + AB_{ij} + e_{ijk}
\]  
(8)

where, \(Y_{ijk}\), \(k\)th replication for the \(i\)th treatment of factor A and the \(j\)th treatment of factor B; \(\mu\), overall mean; \(A_i\), effect of \(i\)th treatment of factor A; \(B_j\), effect of \(j\)th treatment of
factor B; \( AB_{ij} \), interaction effect between A and B; \( e_{ijk} \), random error associated with \( k \)th replication under the \( i \)th treatment of factor A and \( j \)th treatment of factor B.

The subject details are tabulated in Table 2. The experiment is designed with two factors; BMI and chair height are tabulated in Table 3. The factor (B), chair height, has three levels Maximum, Medium and Minimum. Factor (A), BMI, corresponds to eight subjects and hence eight levels. BMI is an outcome of both total weight and height of a human body and hence both these variables can be incorporated in to analysis. In Table 2, every subject has two rows, and the first row is the torque developed at knee during slow BTS and STS, while second row is the torque due to faster action. Hence almost all the factors are inserted into the two-way analysis. \( Y_i \) and \( Y_j \) are the row total and column total.

Table 2  Subject characteristics (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Male subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n=8 )</td>
<td>( n=8 )</td>
</tr>
<tr>
<td>Age (years)</td>
<td>32.5 ± 3</td>
<td>32.5 ± 3</td>
</tr>
<tr>
<td>Range</td>
<td>30–40</td>
<td>30–40</td>
</tr>
<tr>
<td>30–35</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>35–40</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.75 ± 5.238</td>
<td>172.75 ± 5.238</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.5 ± 8.948</td>
<td>80.5 ± 8.948</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.763 ± 2.108</td>
<td>26.763 ± 2.108</td>
</tr>
</tbody>
</table>

BMI, body mass index; \( n \), the number of subjects

Table 3  Torque at knee joint for two factors

<table>
<thead>
<tr>
<th>Body mass index (A)</th>
<th>Chair height (B)</th>
<th>Max.</th>
<th>Med.</th>
<th>Min.</th>
<th>( Y_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>103</td>
<td>200</td>
<td>225</td>
<td>1167</td>
<td></td>
</tr>
<tr>
<td></td>
<td>169</td>
<td>220</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>114</td>
<td>130</td>
<td>200</td>
<td>1055</td>
<td></td>
</tr>
<tr>
<td></td>
<td>174</td>
<td>187</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>138</td>
<td>158</td>
<td>1071</td>
<td></td>
</tr>
<tr>
<td></td>
<td>164</td>
<td>252</td>
<td>239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>218</td>
<td>210</td>
<td>241</td>
<td>1542</td>
<td></td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>303</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>148</td>
<td>209</td>
<td>214</td>
<td>1387</td>
<td></td>
</tr>
<tr>
<td></td>
<td>227</td>
<td>272</td>
<td>317</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>194</td>
<td>217</td>
<td>213</td>
<td>1469</td>
<td></td>
</tr>
<tr>
<td></td>
<td>267</td>
<td>280</td>
<td>298</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Hypothesis**

There are three sets of hypothesis with the two-way ANOVA.

The null hypotheses are stated below.

1. The population means of the first factor (means of row elements) are equal.
2. The population means of the second factor (means of row elements) are equal.
3. There is no interaction between these factors.

The alternative hypotheses are stated below.

1. The population means of the first factor (means of row elements) are unequal.
2. The population means of the second factor (means of row elements) are unequal.
3. There is interaction between these factors.

Null and alternative hypothesis are defined in Table 4.

### Table 4 Null and alternative hypothesis

<table>
<thead>
<tr>
<th>Hypothesis with respect to factor A</th>
<th>Null hypothesis, $H_0$: $A_1 = A_2 = A_3 = A_4 = A_5 = A_6 = A_7$ (Means are equal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate hypothesis, $H_1$: treatment means are not equal for at least one pair of the treatment means of factor A</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hypothesis with respect to factor B</th>
<th>Null hypothesis, $H_0$: $B_1 = B_2 = B_3$ (means are equal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate hypothesis, $H_1$: Treatment means are not equal for at least one pair of the treatment means of factor B</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hypothesis with respect to interaction component AB</th>
<th>Null hypothesis, $H_0$: $A_1B_1 = A_2B_2 = A_3B_3$ … (means are equal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate Hypothesis, $H_1$: Interaction means are not equal for at least one pair of interaction means</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Sum of squares

Two-way ANOVA calculations are explained in Table 5 and its test is conducted in Table 6.

Table 5 Two-way ANOVA calculations

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean sum of squares (MSS)</th>
<th>F ratio</th>
<th>$F(0.05, df = (a, v))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between rows (A)</td>
<td>$a - 1$</td>
<td>$SS_{BMI}$</td>
<td>$\frac{SS_{BMI}}{a - 1}$</td>
<td>MSS$_{BMI}$</td>
<td>$F(0.05, df = (a, v))$</td>
</tr>
<tr>
<td>Between columns (B)</td>
<td>$b - 1$</td>
<td>$SS_{Chair height}$</td>
<td>$\frac{SS_{Chair height}}{b - 1}$</td>
<td>MSS$_{Chair height}$</td>
<td>$F(0.05, df = (b, v))$</td>
</tr>
<tr>
<td>Between rows and columns (AB)</td>
<td>$(a - 1)(b - 1)$</td>
<td>$SS_{Interaction}$</td>
<td>$\frac{SS_{Interaction}}{(a - 1)(b - 1)}$</td>
<td>MSS$_{Interaction}$</td>
<td>$F(0.05, df = (a, b, v))$</td>
</tr>
<tr>
<td>Error</td>
<td>$ab(n - 1)$</td>
<td>$SS_{error}$</td>
<td>$\frac{SS_{error}}{ab(n - 1)}$</td>
<td>MSS$_{error}$</td>
<td>$F(0.05, df = (a, b, v))$</td>
</tr>
<tr>
<td>Total</td>
<td>$N - 1$</td>
<td>$SS_{total}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 Two-way ANOVA test

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean sum of squares (MSS)</th>
<th>F ratio</th>
<th>$F(0.05, df = (a, v))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass index (A)</td>
<td>7</td>
<td>44,326.97917</td>
<td>6332.425595</td>
<td>21.32</td>
<td>3.41</td>
</tr>
<tr>
<td>Chair height (B)</td>
<td>2</td>
<td>26,636.375</td>
<td>13,318.1875</td>
<td>12.81</td>
<td>8.64</td>
</tr>
<tr>
<td>Between body mass index and chair height (AB)</td>
<td>14</td>
<td>7556.958333</td>
<td>539.7827381</td>
<td>0.26</td>
<td>2.35</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>49,894.5</td>
<td>2078.9375</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>12,8414.8125</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total sum of squares ($SS_{total}$) is generally expressed as the summation of sum of squares of factor A ($SS_A$), factor B ($SS_B$), interaction between factor A and factor B ($SS_{AB}$), errors ($SS_{error}$)

$$SS_{total} = SS_A + SS_B + SS_{AB} + SS_{error}$$  \hspace{1cm} (9)

Using (9), total sum of squares ($SS_{total}$) of Table 2 is calculated as the summation of sum of squares of BMI ($SS_{BMI}$), chair height ($SS_{Chair height}$), interaction between BMI and chair height ($SS_{BMI \times Chair height}$), and error ($SS_{error}$)

$$SS_{total} = SS_{BMI} + SS_{Chair height} + SS_{BMI \times Chair height} + SS_{error}$$  \hspace{1cm} (10)
Total number of observations \((N)\) in the experiment is

\[
N = a \times b \times n
\]  

where \(a\), number of treatments for factor A \((a = 8)\); \(b\), number of treatments for factor A \((b = 3)\); \(n\), number of replications under each experimental combination \((n = 2)\).

\[
\begin{align*}
SS_{\text{total}} &= \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{n} y_{ijk}^2 - \frac{Y^2}{N} \\
SS_{\text{BMI}} &= \frac{b}{n} \sum_{i=1}^{a} y_{ai}^2 - \frac{Y^2}{N} \\
SS_{\text{Chair height}} &= \frac{a}{n} \sum_{j=1}^{b} y_{bj}^2 - \frac{Y^2}{N} \\
SS_{\text{subtotal}} &= \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{n} y_{ijk}^2 - \frac{Y^2}{N}
\end{align*}
\]

Total sum of squares of interaction \((SS_{\text{interaction}})\) between BMI and chair height is found by

\[
SS_{\text{interaction}} = SS_{\text{subtotal}} - SS_{\text{BMI}} - SS_{\text{Chair height}}
\]

5 Results and discussion

Test for effect of BMI and chair height on torque at knee during BTS and STS is analysed using ANOVA and those factors interaction is also studied. It is evident from the Table 6, that the null hypothesis is rejected for the factors; BMI and chair height because \(F_{\text{calculated}} > F_{\text{critical}}\). Hence these factors have a significant influence on the torque at the knee joint during BTS and STS. To be more clear and precise: a subject with more BMI applies more torque at the knee joint during STS and BTS movements on a varying chair height. Speed is also a factor which increases the torque requirement at the knee joint. Moreover, the interaction effect is statistically significant because \(F_{\text{calculated}} < F_{\text{critical}}\), and hence the null hypothesis is true for interaction \((AB)\). The effect of BMI on torque depends on chair height and vice versa.

The result obtained from mini tab also justifies the above results by giving a lesser \(R\)-square value, which is an indication for the rejection. Normal probability plot is a graphical technique used to determine the normal distribution of the data. The normal distribution is obtained if a straight line is obtained when plotting the residual against its percentage. Normal probability plot in Figure 3 shows that the output variable torque is almost normally distributed even though the graph is not a perfect straight line. This probability criterion meets the requirements for ANOVA analysis. In the residual frequency distribution histogram, the highest frequency of occurrence is 12 for residual 30. Moreover, the higher residual values occur at a lesser frequency, which in fact justifies the correctness of the predicted model and hence the fit. Also residual varies
from $-60$ to $+60$, which indeed shows the error between the fitted value and the observed value are not much higher enough to reject the hypothesis. This residual variation is the real effect of lesser $R$-square interaction value.

**Figure 3** Residual plot for torque showing normal probability and fit in (see online version for colours)

Hence the knee joint of a robot, exoskeleton or an assistive device should be designed in such a way that it should be capable of developing adequate torque at its knee joint, if its weight is higher or if it is designing for BTS and STS. Either considerable reduction in exoskeleton’s weight should be made or design should be optimised to reduce its weight, without compromising the functionality, in order to supply the adequate torque at the knee joint for its smooth movement. In addition, if it carries any higher weights at the back, it will positively affect the torque requirement.

Table 7 shows the comparison of required torque during knee flexors and extensors between earlier studies (Schultz et al., 1992) and current study. In earlier studies, torque was calculated as the percentage of the total torque required whereas Lagrangian formulation for the dynamic torque calculation at Joints is used in the current study. Moreover, three-dimensional mathematical modelling of human leg is used for the joint torque calculation in this study while two-dimensional modelling in the old study. This justifies the accuracy of these findings.

<table>
<thead>
<tr>
<th>Source</th>
<th>Knee flexors</th>
<th>Knee extensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knapic et al. (1983)</td>
<td>290</td>
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</tr>
<tr>
<td>Borges (1989)</td>
<td>310</td>
<td>578</td>
</tr>
<tr>
<td>Dannenskiold et al. (1984)</td>
<td>–</td>
<td>150</td>
</tr>
<tr>
<td>This study</td>
<td>295</td>
<td>425</td>
</tr>
</tbody>
</table>
6 Conclusion

A two factor ANOVA analysis is performed for studying the effect of BMI and chair height on the torque produced at the knee and it is proved that these factors definitely influence the torque developed at the knee.

Torque required at the knee is directly proportional to the magnitude of these factors. As torque required at the knee joint is more, when the subject's BMI is higher or the chair height is lower than 50 cm, it is advisable to use some external support by high BMI people, while performing STS and BTS movements on a chair with height lower than 40 cm. Thus, the torque is multiplied as a combined effect of chair height and BMI, which really explains the interaction between chair height and BMI.

When a subject tries to do these movements faster, the torque requirement at the knee joint is also getting increased. Hence precautions should be taken by subjects, with higher BMI, while performing BTS and STS movements on a varying chair height in a faster manner in order to avoid knee injuries or damage, due to high torque. The major concern in designing a exoskeleton is about the actuator selection for knee and hip actuations, as it should replicate most similar behaviour of human muscles in order to produce a natural human locomotion.

It has been observed that the trajectory formed when performing BTS and STS follows a different path. This difference in trajectory clearly speaks about the shifting of upper body centre of mass along horizontal axis and hence more torque is required at joints to hold this in position, can be analysed further based on torque at knee and hip joints.

References

Effect of body mass index and chair height


