Original article

Effect of table top slope and height on body posture and muscular activity pattern

Effet de l'inclinaison et de la hauteur de la table sur la posture et le patron d’activité musculaire

M. Hassaïne a,b, A. Hamaoui a,b, P.-G. Zanone b

a Laboratory of Posture and Movement Physiology, University Champollion, place de Verdun, 81000 Albi, France
b PRISMMH, University of Toulouse, University Paul Sabatier, 31000 Toulouse, France

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A B S T R A C T

The objective of this study was to assess the effect of table top slope and height on body posture and muscular activity pattern. Twelve asymptomatic participants performed a 5-min reading task while sitting, in six experimental conditions manipulating the table top slope (20° backward slope, no slope) and its height (low, medium, up). EMGs recordings were taken on 9 superficial muscles located at the trunk and shoulder level, and the angular positions of the head, trunk and pelvis were assessed using an inertial orientation system. Results revealed that the sloping table top was associated with a higher activity of deltoideus pars claviculairis (P < 0.05) and a smaller flexion angle of the head (P < 0.05). A tentative conclusion is that a sloping table top induces a more erect posture of the head and the neck, but entails an overload of the shoulder, which might be harmful on the long run.

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R É S U M É

L’objectif de cette étude a été d’évaluer l’effet de l’inclinaison et de la hauteur de la table sur la posture et le patron d’activité musculaire chez l’être humain. Douze sujets asymptomatiques ont réalisé une tâche de lecture de 5-min en posture assise, au cours de six conditions expérimentales faisant varier l’inclinaison (pas d’inclinaison, inclinaison en arrière) et la hauteur (basse, moyenne, élevée) du plateau de la table. Les signaux EMG ont été enregistrés sur neuf muscles superficiels du tronc et de l’épaule, tandis que les positions angulaires de la tête, du tronc et du bassin étaient évaluées au moyen d’une centrale inertielle. Les résultats ont montré que lorsque le plateau était incliné, la flexion de la tête était réduite (p < 0.05) et l’activité du deltoïde antérieur plus élevée (p < 0.05). Il en est conclu que les tables avec plateau incliné favorisent une posture plus droite de la tête et du cou, mais génèrent au niveau de l’épaule une charge additionnelle qui pourrait être nocive sur le long terme.

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1. Introduction

During the last decades, the growing use of biomechanical tools (EMG, video analysis, force plates, pressure measurement) in the field of human movement analysis has fostered many studies exploring the effect of work station design on the biomechanical strain sustained by the body [1–4]. However, few studies were devoted to an in-depth exploration of the influence of table height and slope on body posture and muscular activity. Using inclinometers (statometric method) and EMG recordings of trapezius pars descendens, Bendix and Hagberg [5] found that the head and trunk moved to a more upright posture with sloping desks (22° and 45°). However, no concurrent variation was found in the EMG data. In another study using inclinometers [6], similar results were found for body posture, with a more erect position of
the head (+6°) and the trunk (+7°) when sitting with a 10° sloping desk. Still based on inclinometer recordings, another experiment [7] confirmed this phenomenon, with a more upright posture of the head (+8.9°) and the trunk (+7.8°) when using a 10° sloping desk. These findings are in line with a host of results gathered through a less accurate technique, which consists of video recording with adhesive markers placed on the trunk and the lower limbs [3,8]. Indeed, Bridger [3] depicted a lower trunk and neck flexion, and Mandal [8] reported that the neck angle was reduced with a 15° sloping table. However, besides Mandal’s experiment [8], none explored the effect of table height.

To our knowledge, no extensive EMG measurements have been performed so far under varying conditions of table slope or height, with the exception of a single study that only focused on trapezius pars descendens [5]. As a consequence, little is known about the adaptation of the postural muscles pattern under these different conditions, about its relation with posture, or about the risk of muscular fatigue. The issue of the sliding effect of a sloping desk on the forearms and its consequences on muscular activity at the shoulder level also remains to be explored. Such findings would be quite relevant to determine the extent to which a sloping table top, advocated by many authors [3.5–9], is instrumental in reducing the biomechanical load sustained by the postural chain.

The general purpose of the present study was to assess the effect of table height and slope on body posture and on muscular activity along the neck, trunk and shoulders. To this aim, EMG recordings and angular position measurements were taken while sitting with two slopes and three heights of the table top.

2. Method

2.1. Participants

Twelve asymptomatic male participants, free of any neurological or musculo-skeletal disease, took part in the study. Mean age (± SD) was 20.4 (± 1.5) years, with a mean weight of 72.9 (± 8.8) kg, a mean height of 179 (± 5) cm, and a mean body mass index of 22.8 (± 2.5) kg.m⁻². The study was approved by the local ethics committee, and complied with the Helsinki declaration. All participants gave their written informed consent prior to the experiments.

2.2. Materials

2.2.1. Electromyography

A 16-channel wireless EMG device (Zero Wire model, Aurion, Milan, Italy) was used to quantify the normalized surface electrical activity of trunk and shoulder muscles.

Nine superficial muscles of trunk and shoulder were selected after a pre-test series: neck extensors, trapezius pars descendens, trapezius pars ascendens, deltoideus pars clavicularis, rectus abdominis, latissimus dorsi, erector spinae at T4, T11 and L3 levels.

The participant’s skin was shaved where needed, abraded and cleaned with alcohol to reduce skin impedance to below 5 kΩ. 10-mm diameter (conductive area) Ag/AgCl pre-gelled disposable surface electrodes (PG105, FIAB, Vicchio, Italy) were applied in a bipolar configuration over the muscle belly parallel to the muscle fibres direction, on the dominant side of the body. The inter-electrode distance was 20 mm for all sites. All electrode placements were validated using palpation and manual resistance tests. Recordings were next taken during the six experimental conditions in a sitting posture.

To allow for normalization of the EMGs signals by their maximum values, two 3-s isometric maximal voluntary contractions (MVC) were first carried out for each muscle. The normalization procedure was used to limit the inherent EMG signal variability due to electrode application, perspiration, temperature and subcutaneous fat thickness [10].

The individual EMG signals were digitized at 1000 Hz using aCompactDAQ with 9215 modules (National Instrument, Austin, USA), controlled by a custom program written using Labview (National Instrument, Austin, USA). For each muscle, average rectified EMGs were calculated from the complete recordings, and the values were expressed as a percentage of the data obtained in MVC (normalized EMG).

2.2.2. Inertial orientation system

The angular position of the head, spine and pelvis was measured by means of a three-degree-of-freedom orientation inertial system (Inertia Cube3, Intersense Inc., Billerica, USA), composed of three wireless trackers (IC3) transmitting data to a USB receiver connected to a computer. Each tracker contains 3 integrated sensors in each orthogonal plane: a rate gyroscope, a uniaxial accelerometer and a magnetometer, which measure the angular velocity, the acceleration and the Earth’s magnetic field, respectively. Data from the three sensors are integrated and processed using Kalman filter, to display the orientation as Euler angles (yaw, pitch and roll). According to the manufacturer, the RMS accuracy is 1° in yaw, 0.25° in pitch and roll. Orientation data were collected and synchronized with the EMG signals, using a custom Labview-based program (National Instrument, Austin, USA).

The first tracker was placed on the top of the head, at the junction between the two parietal bones, using a system of Velcro bands. The second and the third trackers were adhered to the skin with double sided tape, at the levels of T1 and S1 spinous processes (Fig. 1). These trackers provided data representing the absolute angular position of different body segments in the three orthogonal planes. As this study focused on the effect of a sloping table top on posture, only data recorded in the sagittal plane will be presented. Mean values and standard deviations of head flexion (tracker 1), trunk flexion (tracker 2), and anterior pelvic tilt (tracker 3) were calculated for each trial.

2.2.3. Table and chair

A chair and a table (Héphaïstos, Rivière-sur-Tarn, France), both adjustable in height, were used for the experiment (Fig. 2). The chair had a flat seat, and the top of the table was tiltable from 0° to 20°. A special steel ruler elevated at the rear-end was mounted on the table top to prevent the book from sliding.

2.3. Procedure

2.3.1. Anthropometric measurements

To adjust the seat and table heights according to each participant’s anthropometric characteristics, three parameters were measured prior to the testing, using a tape measure:

- popliteal height (PH): distance from the floor to the popliteal fossa, participant standing barefoot;
- elbow height (EH): distance from the seat to the olecranon process, participant sitting with elbows flexed at 90°;
- shoulder height (ShH): distance from the seat to the acromio-clavicular joint.

2.3.2. Experimental conditions

For all trials, the participants were required to adopt the most comfortable posture, while sitting to the back of the chair with their forearms resting on the table. They wore long sleeves cut off from a stretchable top in order to keep the friction between the table and the forearms constant. During the whole recording, they had to read a short-format novel that laid flat at the centre of the table top.
One 5-min recording was taken in 6 different experimental conditions, varying table top slope (no slope, S0; 20° slope, S20) and height (up, Hup; medium, Hmed; low, Hlow). A 2-min rest period was given between trials. The order of the experimental conditions was assigned in a random fashion to prevent any order effect.

The three table height (TH) levels were calculated from the equation of Gouvali and Boudolos [11] (1), which defines the range of recommended table height.

\[
EH + [(PH + 2) \cos 30^\circ] \leq TH \leq [(PH + 2) \cos 5^\circ] + (EH0.8517) + (SH0.1483)
\]

where \( TH \) was the vertical distance from the floor to the top of the back edge of the table.

The “up” position (Hup) was the upper bound of the equation plus 10%:

\[
Hup = 1.1[(PH + 2) \cos 5^\circ] + (EH0.8517) + (SH0.1483)]
\]

The “medium” position (Hmed) was the upper bound of the equation:

\[
Hmed = [(PH + 2) \cos 5^\circ] + (EH0.8517) + (SH0.1483)
\]

The “low” position (Hlow) was the lower bound of the equation

\[
Hlow = EH + [(PH + 2) \cos 30^\circ]
\]

No setting was taken below the lower bound of the equation, as the table clearance was in this case too low to avoid any contact between the thighs and the table.

The mean ± SD of table height was 65 ± 3 cm for Hlow, 77 ± 3 cm for Hmed, and 85 ± 4 cm for Hup.

In every condition, the seat height (SH) was set at the upper bound of the equation proposed by Gouvali and Boudolos [11] (2), which was judged to be more comfortable than the lower bound in the pre-test series.

\[
(2)SH = (PH + 2) \cos 5^\circ
\]

The mean ± SD of seat height was 46 ± 2 cm.

### 2.3.3. Numeric comfort scale

At the end of the experiment, the participants had to rate each sitting condition on a five-point comfort scale, where a score of 1 corresponded to “not comfortable at all” and a score of 5 to “very comfortable”.

### 2.4. Data analysis

Mean normalized EMGs of the selected 9 muscles and the mean angular position of the head, T1 and S1 in the sagittal plane provided 12 dependent variables. The independent variables were:

- the table top slope with two levels: 0° and 20°;
- the table height with three levels: up, medium and low.

A two-way repeated-measures analysis of variance (ANOVA) was conducted for each dependent variable, with the table top slope and table height set as within-subjects factors. Interaction between table slope and height was also tested for each dependent variable. When statistical significance was reached for table height factor, the analysis was completed by within-subjects contrasts to compare levels. The significance level was set at \( P < 0.05 \). The analysis was performed using Statistical Package for Social Sciences (SPSS) software V14.0 (Chicago, USA).
3. Results

3.1. EMG measurements

Normalized EMG of deltoideus pars clavicularis was greater when the table top was set in the sloping position (S20 condition) compared to the flat position (S0 condition) \((P < 0.05)\) (Fig. 3). A similar trend was observed for trapezius pars descendens, erector spinae T11 and erector spinae L3, but with no significant variation (Table 1).

Normalized EMG of trapezius pars descencens also increased with table height and presented a significant variation between Hlow and Hup conditions \((P < 0.05)\) (Fig. 4). In the same way, the mean value of neck extensors increased stepwise from Hlow to Hup conditions in S0 and S20 (Table 1), but with no statistical significance.

3.2. Angular position measurements

Data from the inertial sensors revealed substantial variations as a function of table slope and height. Head flexion angle was smaller with a sloping table top (S20) than with a flat table top (S0) \((P < 0.05)\) and also decreased from Hlow to Hup \((P < 0.01)\) (Fig. 5, Table 2). T1 flexion presented the same trend for table slope and height, but statistical significance was reached only for table height \((P < 0.01)\) between Hlow and Hup, \(P < 0.05\) between Hlow and Hmed (Table 2).

No significant variation or relevant trend was observed for S1 tracker (Table 2).

3.3. Comfort scale

The subjective assessment of comfort using the numeric comfort scale revealed no variation as a function of table slope. In contrast, significant variations were observed according to table height, with the best score reached for Hmed \(P(Hmed/Hup) < 0.05, P(Hmed/low) < 0.01\) (Fig. 6).

4. Discussion

Results from EMGs measurement revealed that sitting with the forearms resting on a sloping table top (S20 condition) is associated with a higher activity of deltoideus pars clavicularis. This phenomenon can be explained by the effect of sliding down resulting from the additional tangential component of gravity force that appears when gravity is no more perpendicular to the top surface. To keep the forearms still on the table, this component should be balanced by an opposite force, likely produced by the deltoideus. This higher activity of deltoideus could lead to inner muscular fatigue if it occurs for a long period of time. It should also increase the stress sustained by the glenohumeral joint, which might be harmful on the long run. This may represent a major drawback for tables with sloping top, which has so far not been pointed out in the literature.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>S0 Hlow</th>
<th>S0-Hmed</th>
<th>S0-Hup</th>
<th>S20-Hlow</th>
<th>S20-Hmed</th>
<th>S20-Hup</th>
<th>PS0/S20</th>
<th>P(Hover)</th>
<th>P(Hlow/Hup)</th>
<th>P(Hlow/Hmed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck Ext</td>
<td>21.44 ± 8.7</td>
<td>22.03 ± 9.6</td>
<td>22.57 ± 11.5</td>
<td>21.18 ± 10.8</td>
<td>23.37 ± 14.5</td>
<td>25.11 ± 15.6</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Trap PD</td>
<td>3.20 ± 3.5</td>
<td>6.91 ± 7.0</td>
<td>6.74 ± 5.5</td>
<td>7.46 ± 4.6</td>
<td>7.53 ± 5.2</td>
<td>10.93 ± 6.2</td>
<td>NS</td>
<td>P &lt; 0.05</td>
<td>P &lt; 0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Delt PC</td>
<td>0.72 ± 0.3</td>
<td>1.07 ± 0.7</td>
<td>0.62 ± 0.3</td>
<td>1.29 ± 0.8</td>
<td>0.62 ± 0.2</td>
<td>1.34 ± 0.7</td>
<td>P &lt; 0.01</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Trap PA</td>
<td>2.30 ± 2.6</td>
<td>3.14 ± 1.8</td>
<td>2.77 ± 2.0</td>
<td>3.04 ± 1.6</td>
<td>2.65 ± 1.4</td>
<td>2.57 ± 1.1</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>ESpi T4</td>
<td>3.38 ± 1.3</td>
<td>4.31 ± 1.5</td>
<td>3.62 ± 1.7</td>
<td>4.21 ± 1.7</td>
<td>4.17 ± 1.4</td>
<td>3.77 ± 1.6</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>ESpi T11</td>
<td>4.45 ± 3.0</td>
<td>7.43 ± 4.7</td>
<td>5.59 ± 4.0</td>
<td>8.15 ± 4.8</td>
<td>7.72 ± 4.3</td>
<td>7.86 ± 4.5</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>ESpi L3</td>
<td>5.57 ± 1.8</td>
<td>4.63 ± 2.6</td>
<td>3.55 ± 1.8</td>
<td>4.71 ± 2.8</td>
<td>4.81 ± 2.5</td>
<td>4.15 ± 1.7</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Lat Dorsi</td>
<td>2.38 ± 1.0</td>
<td>2.44 ± 1.1</td>
<td>2.29 ± 1.0</td>
<td>2.48 ± 1.1</td>
<td>2.48 ± 1.1</td>
<td>2.53 ± 1.0</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Rect Abd</td>
<td>3.84 ± 3.3</td>
<td>3.85 ± 3.2</td>
<td>3.19 ± 2.8</td>
<td>4.13 ± 3.3</td>
<td>3.98 ± 3.3</td>
<td>4.16 ± 3.9</td>
<td>NS</td>
<td>NS</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

NS: non significant; NA: not available.

Data from nine superficial muscles are presented: neck extensors (Neck Ext), trapezius pars descendens (Trap PD), deltoideus pars clavicularis (Delt PC), trapezius pars ascendens (Trap PA) erector spinae at T4 level (ESpi T4), T11 level (ESpi T11) and L3 level (ESpi L3), lattissimus dorsi (Lat Dorsi), rectus abdominis (Rect Abd). The table settings combine two slope levels (S0 and S20) and three height conditions (Hlow, Hmed and Hup). Mean ± SD are expressed as a percentage of the values recorded in the MVC test of each muscle. For table height, the overall effect (HOverall) and the contrast analysis between Hlow/Hup and Hlow/Hmed are described.
Table 2
Angular positions as a function of table slope and height (').

<table>
<thead>
<tr>
<th></th>
<th>Head flexion</th>
<th>T1 flexion</th>
<th>S1 Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0 Hlow</td>
<td>51 ± 12</td>
<td>64 ± 14</td>
<td>2.17 ± 8</td>
</tr>
<tr>
<td>S0-Hmed</td>
<td>46 ± 12</td>
<td>59 ± 14</td>
<td>1.84 ± 11</td>
</tr>
<tr>
<td>S0-Hup</td>
<td>40 ± 11</td>
<td>52 ± 10</td>
<td>-4.64 ± 11</td>
</tr>
<tr>
<td>S20-Hlow</td>
<td>34 ± 10</td>
<td>57 ± 17</td>
<td>0.38 ± 10</td>
</tr>
<tr>
<td>S20-Hmed</td>
<td>36 ± 10</td>
<td>55 ± 13</td>
<td>2.86 ± 9</td>
</tr>
<tr>
<td>S20-Hup</td>
<td>29 ± 10</td>
<td>49 ± 10</td>
<td>0.10 ± 11</td>
</tr>
<tr>
<td>P(S0/S20)</td>
<td>P &lt; 0.05</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>P(HOverall)</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.01</td>
<td>NA</td>
</tr>
<tr>
<td>P(Hlow/Hup)</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.01</td>
<td>NA</td>
</tr>
<tr>
<td>P(Hmed/Hlow)</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.05</td>
<td>NA</td>
</tr>
</tbody>
</table>

NS: non significant; NA: not available.

Data from the inertial orientation system showed that a sloping table top was associated with a significantly lower flexion of the head, i.e. it was positioned in a more erect posture. These results are in line with previous studies describing a more upright posture of the head and trunk with inclined desks [3.5–8]. They could be explained by the reduction of the eye-to-object distance resulting from the backward tilt of the top surface, which requires a smaller head flexion for an equivalent eye accommodation. This might also explain the significant reduction of head and trunk flexion with the increasing height of the table (Hlow/Hmed and Hlow/Hup).

As a smaller head extension reduces the lever arm of the destabilizing torque due to gravity, it can be assumed that the theoretical load sustained by the cervical spine is lower when using a sloping table top. This assumption is supported by in vivo measurements of lumbar intra-discal pressures, denoting a higher intra-discal pressure when the spine is flexed [12–14]. Although these studies focused on the lumbar spine section only, one can assumed that the mechanical effect of the vertebral flexion on the neighbouring discs occurs at the cervical level too.

Data from S1 tracker and from muscles located under the shoulder level did not show any significant variation as a function of table height and slope, suggesting that table settings have a limited influence on the lower half of the trunk and on the pelvis.

Contrary to the angular position of head, normalized EMGs of the 8 trunk and neck muscles (trapezius pars descenscens, neck extensors, trapezius pars ascendens, rectus abdominis, latissimus dorsi, erector spinae at T4, T11 and L3 levels) did not vary significantly as a function of the table slope. Higher mean values of trapezius pars descendens EMG were observed in S20 compared to S0, but statistical significance was not reached, similarly to the study by Bendix and Hagberg [5]. One explanation may be that the angular variations of head flexion (less than 20°) were not important enough to require a detectable raise of the EMG activity.

In this case, the additional forces produced to stabilize the more flexed head could be due to passive mechanisms. Indeed, the stretching of the passive soft tissues surrounding the cervical vertebrae and of the elastic component of the neighbouring muscles may provide a resistive tension balancing the greater destabilizing torque due to gravity. This mechanism might explain why many people feel more comfortable in a relaxed or slumped posture, which involves less muscular activity than an erect one [15–18] and leads to the cervical flexion-relaxation phenomenon when cervical flexion is complete [19]. Hence, higher mechanical load on a joint is not necessarily associated with a higher muscle activity and risk of fatigue, as stability can be provided by both active and passive sources of force.

Results from the comfort scale questionnaire did not reveal any variation according to seat slope: there is no correlation between the user experience and the estimated load variations at the shoulder and neck levels. This could be related to the short time of the experiments that limits the harmful effect of muscular activity and angular position, whose variations are intrinsically low. Contrasting with the sloping parameter, table height displayed significant variations of the comfort score, with the medium height presenting the best rating. This finding suggests that attention should be paid to the adaptation of table height in a working environment or at school. The choice of the most appropriate size or height setting for adjustable tables is thus a significant input to improve the user experience.

In the present study, some methodological issues need to be addressed. First, all recordings were taken during a reading task, so that it cannot be excluded that postural adaptation to a sloping table top is somewhat different from a writing situation. This should nevertheless be pondered, as our findings on head and trunk flexion are consistent with other studies using a handwritten work [3] and a mixed reading/writing activity [6,7]. Second, only surface EMG was recorded, while some variations may only occur in the deep layers of postural muscles. As an example, slight differences were observed between deep and superficial multi-fidus when maintaining different thoraco-lumbar curves in a seated posture [15]. Hence, the use of intramuscular EMG in future experiment may reveal some specific variations that were not detected in the present study.

5. Conclusion

Sloping table top favours a more erect posture of the head and a reduction of the stress sustained by the neck. However, it is associated with a higher activity of the deltoideus pars clavicularis, aimed at preventing the sliding down of the forearms but that may lead to an overload on the shoulders. Its use at school or in a working environment has to be considered with cautious.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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