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Why Should we Use Inclined Tables in Engineering Drawing Works?

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Abstract: One of the primary purposes of studying human Factors is to relieve work stresses imposed on the workers during their jobs. The current study consisted of two stages. The first phase aimed to develop a microcomputer biomechanically based to analyze clerk body postures. The second phase was to test that developed model on studying table tapes (i.e., adjustable inclined versus table vs. fixed horizontal table) during drawing engineering designs. The results showed the capability of the proposed model for analyzing the clerks' jobs. In addition, the inclined furniture was superior in reducing the stresses associated with doing jobs using furniture compared with fixed horizontal tables. Finally, it would be better to use a simple tool such as the developed one to analyze complicated tasks that force workers to take awkward postures and sustained that posture for an extended period.

Keywords: Biomechanics, Furniture, Human Factors, Engineering.

1. INTRODUCTION

The majority of engineering drawing jobs require a man to remain at his posture for the workday duration, and many employees spend their entire careers in one occupation. The cumulative effects of several years of work at insufficiently designed workplaces in terms of capacities and measurements can be highly detrimental to the musculoskeletal systems.

Musculoskeletal injuries were the top priority in daily medical practice in most cases [1,2]. Recent research in the revelation claims that over one million people with MSD were unable to function last year, with an annual economic loss exceeding $50 billion [3]. Approximately 6.4% of Australia's entire workforce (who have worked at least one year after a work-related injury) has reported at least one injury or illness in the past year [4]. A large number of injuries and diseases are connected to jobs in the U.S. That equates to roughly 15-20% of all Americans [5].

Oakman et al. [6] identified an association between MSP and adverse physical and psychosocial job characteristics in their study of the relationship between pain site and workplace characteristics for use by individual participants. Organizations must conduct a thorough assessment of their work environments to ensure that all potential workplace risks, both physical and psychosocial, are recognized and then mitigated for all age groups. According to Jay et al. [7], increased stress and musculoskeletal discomfort are associated with decreased work capacity in female laboratory technicians. Floyd and Ward [8] demonstrated how two operators' bent upper spines resulted in them operating at a too low pace for their heights. One of the numerous studies has addressed the importance of correcting work postures to improve work efficiency and productivity. Brideger [9] showed that sloping furniture significantly decreased trunk flexion. The knee, hip joints, and pelvis adapted to the forward-sloping chair, while the neck and trunk inclination adapted to the eloping table floor. Additionally, sloping furniture was viewed as providing a more relaxing feeling than standard furniture. Even with humans come in different sizes where there are differences between different national, ethnic groups, there are gender differences.

With the rapid computing capabilities of modern microcomputers, it becomes both scientifically beneficial and economically feasible to conduct comprehensive mechanical analyses of people's interactions with their tasks and work environment. A generalized model capable of predicting and quantifying work-related stresses may be helpful. This article describes a microcomputer-based model for calculating the compression load on body joints in the upper limbs. This interactive model will assist job designers in evaluating secure compression loads for workplace design, optimize material handling, optimize physical (seat, worktop, etc.), and visual (display and tool placement) posture. In addition, the program will test its capability to identify which furniture is appropriate to be used for engineering drawing task supporting with applying Electromyography (EMGs) signals and subjective measures.

2. METHODS

This article is divided into two phases. The first phase was developing the micro-computer biomechanical model. Then, the second phase was testing and applying this model to differentiate between furniture designs.

2.1 Phase I. Developing the Microcomputer Model

The proposed model is similar to that one developed by Khalid and Ramadan [10], except that the proposed model allowed the person to support his/her hands or arms on an object. The proportions of the individual body's components are just as significant as the total size and weight. A popular approach is to view the human body as a series of pieces, as illustrated in Figure 1. The components are linked through articulation points.

Figure. 1 Body Link System.

The biomechanical model aimed to determine the stresses placed on the musculoskeletal system's critical points. The model uses currently available data on body segment parameters, assuming that the body is composed of rigid links connected at predetermined articulations. The reactive forces and torques equations at the various articulations of the body in various configurations could be constructed using these segment parameters and Newtonian mechanics. The human body is modeled in Figure 2 as a two-dimensional, eight-link structure representing movement across seven joints. The foot, knee, back, L5/S1, shoulder, elbow, and wrist are all included. Since most back injuries occur in the lower back at the level of the fifth lumbar and first sacral vertebrae (L5/S1) and their adjacent disc, cumulative loads impose stresses on that area. The trunk was divided into two parts to allow for the measurement of spinal compressive forces and moments at the L5/S1 disk: (1) Hip joint to L5/S1 disc center; (2) L5/S1 disc center to shoulder joint. The ankle joint is believed to be fixed in place, serving as a reference point for the model.

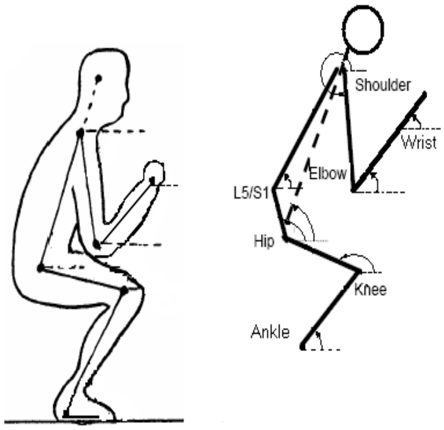

Fig. 2. Linkage system used in body model.

Angles between body links and the horizontal, measured in an anticlockwise direction, describe posture. Angles θ3 and θ4 are calculated in the model using the inclination of the trunk and knee relative to the horizontal θ8 and θ2 [11]. The model will be implemented using an advanced Visual Basic program. The software will make use of both stored and user-supplied data. The data that is stored includes the following:

1) The weight of the body segment links which is based on the ratios of segment weight to body weight based on data provided by Miller and Morrison [12] as shown in Table 1.
2) Location of the center of gravity for each link based on data provided by Garg and Chaffin [13] as shown in Table 2.
3) Radius of rotation for each link as given by Chaffin and Anderson [14].

To ensure that the L5/S1 disc does not experience excessive stress during static and dynamic analysis, the model assumes that safe stress exists when the maximum compression force measured on the spine is less than the compressive force limits specified by Chaffin and Anderson [14]. Males have a mass of 5670 N (578 kg), and females have a mass of 3394 N (346 kg). The maximum weight lifted in a given configuration is determined by assuming that the same permissible weight limit on the L5/S1 is not exceeded. Biomechanical analysis may be conducted in either a dynamic or static mode using the model.

Table 1. Body segment weight as a presented regression equation SW= a + b * TW based on Miller and Morrison [12].

Body segment	a	b
Hand	+0.7	+0.01
Forearms	-0.5	+0.04
Upper arms	-2.9	+0.8
Head, neck and trunk	+12.0	+0.47
Upper legs	+3.2	+0.18
Lower legs	-1.9	+0.11
Feet	+1.5	+0.02

TW= total body weight in lbs. SW= segment weight in lbs.

Table 2. Link centers of mass as a percentage of segment length based on Garg and Chaffine [13].

Segment	from proximal end	from distal end
Hand	50.6%	49.4%
Forearms	43.0	57.0
Upper arms	43.6	56.4
Head, neck and trunk aboveL5/S1	43.21	56.79
Trunk below L5/S1 disk	50.0	50.0
Upper legs	56.7	43.3
Lower legs	56.	43.3
Feet	57.1	42.9

2.1.1 *Static mode analysis*

The static analysis mode uses the same body segment data as the dynamic analysis mode, except all accelerations are set to zero, and ∑Fx and ∑Fy are equal to zero. By defining the body posture, the static model is initiated. Six articulation angles can be used to describe a person's stance. These are the angles at the ankle, knee, trunk, shoulder, elbow, and wrist. These could be determined using photographic techniques based on a lateral photograph of a worker in the role understudy and similar to that used in Chaffin and Anderson [14]. All angles are determined in the opposite direction of the horizontal plane, counter-clockwise. After defining a body position, the model measures the inclination angles of both the hip-L5/S1 and L5/S1 shoulder links using the trunk and knee angles with the horizontal plane. The masses of the body segments produce the joint forces and torques.

A function of the model is intended to identify essential postures associated with a given task at a given height. This is the case of the position in which the L5/S1 stresses exceed the compressive force maximum. Within the range of motion, the body articulation angles are incremented using maximum, minimum, and increment values stored in the software memory. Each articulation angle is then decreased or increased incrementally to create a logically balanced posture. This process is repeated for each articulation angle until all possible positions have been considered.

2.1.2 *Dynamic mode analysis*

For dynamic analysis, the body's inertia generates forces that are a component of the overall kinematics mechanism. This model is based on a relationship established many years ago by Slot and Stone [15] to explain the displacement—time relationship for arm movement. By examining segment displacements concerning time, the angular velocity and acceleration are calculated using the displacement equation's first and second derivatives. Beginning with the ankle joint, the tangential and regular accelerations, as well as their horizontal and vertical components, will be calculated at each segment's center of gravity using the following equations:

$$\text{Tangential acceleration} = \omega_i * r_i$$

$$\text{Normal acceleration} = \alpha_i * r_i$$

Where:

r_i = the distance of the center of gravity of segment i to the articulation;

ω_i = angular velocity of segment i;

α_i = angular acceleration of segment i.

At the center of mass of each segment, the inertial force components in the X and Y directions are determined by multiplying the link mass by the corresponding linear acceleration components. Forces and torques are measured at each joint using the equilibrium equations, taking into account the mass of the body segments, the mass of the handled weight, and the additive effects of acceleration on both the weight handled and the body segments. This study requires a detailed explanation of the motion of each connection during work activities. This can be accomplished using photographic data captured with either a goniometric or video spot locator device [14]. The entire movement should be photographed from start to finish. The data are entered into the computer program either by specifying postures at constant time intervals or by specifying the posture that corresponds to the actual elapsed time.

2.1.3 *Model input/output*

The required input data include the subject's weight, gender, and connection lengths (i.e., the straight-line distances between the articulation points). The latter is calculated either from actual body dimensions or from a displaced table of percentile values. At this point in the program's implementation, two choices would be available for calculating the mechanical stresses in the body. The user can choose any choice from the menu. If the static choice is chosen, the user must enter body posture parameters that correspond to the links' angle relative to the horizontal. If the dynamic choice is chosen, the consumer must supply body posture angles at various time intervals along the motion trajectory.

The seven postural angles are defined as follows:

1) Trunk Flexion Angle (TF): The angle between the upper trunk line and the upward extension of the pelvic line. The angle TF increases with increased bending of the trunk.
2) Hip Flexion Angle (HF): The angle between the thigh and the downward extension of the pelvic line. The angle HF increases as the hip joints are flexed.
3) Pelvic Inclination Angle (PI): The inclination of the pelvic line with respect to the horizon tab PI decreases as the pelvis tilts backward.
4) Trunk Inclination Angle (TI): The inclination of the trunk with respect to the horizontal. Large values of TI represent an upright posture, whereas small values are observed when the trunk is inclined over the work surface.
5) Thigh Angle (TH): The inclination of the thigh with respect to the horizontal. TH increases as the thighs are pointed downward. TH was given a negative sign if the thighs pointed above the horizontal.
6) Neck Flexion Angle (NF): The angle between the upward extension of the trunk line and the line from the seventh cervical marker through the subject's eye. NF increases as the head is bent forward with respect to the trunk.
7) Knee Flexion Angle (KF): The angle between the lower leg line and the extension of the thigh line. KF increases as the knee is flexed.

Those angles are inputted in the model microcomputer with other measures (weight, anthropometric measurements) to get results.

The following output data will be printed by the microcomputer model:

1) A complete configuration for a given motion or for a defined posture.
2) Position of each joint in the space (Cartesian Coordinates) considering the ankle joint as a reference.
3) Angular velocity and acceleration for each link.
4) Forces in the X and Y directions at each joint.
5) Torque at each joint.
6) Compression force at L5/S1 joint.

In addition to the above information, special messages may appear depending on the option selected.

2.2 Phase II. Model Testing

In the second phase, an experimental method was employed to test the developed biomechanical model and the significance of using inclined adjustable furniture. Again, biomechanical body stresses, muscular activities, and subjective measures were the dependable factors; while table types (e.g., adjustable inclined versus fixed horizontal table) were independent factors.

2.2.1 *Participants*

The participants were eight unpaid male engineering students. The mean age of the participants was 23 years, their average height was 167.7 cm, and their average weight was 75.2 kg. The experiment excluded all participants who were obese or had a history of musculoskeletal disorders. The experiment requires participants to draw on two different kinds of tables: a horizontal surface and an adjustable inclined table, as shown in Figure 4, over a forty-five-minute period for each run.

2.2.2 *Dependent variables*

2.2.2.1 Biomechanical model

It is described in detail in phase I.

2.2.2.2 Electromyography (EMG)

Electromyography is a medical procedure used to determine the response of muscles to nerve stimulation. Electromyography measures the electrical potential produced by contracting muscle cells. When a muscle fiber twitches, a small electrical potential is produced that can be measured by inserting an electrode into the muscle or above the muscle on the skin's surface. (Surface electrodes are usually less invasive and are used in laboratory and workplace experiments.) Since the relationship between muscle force and electrical output is monotonic, calibration procedures are used to translate EMG signals to estimates of muscle force output.

During execution sessions, EMG values such as root mean square (RMS) and rectified absolute mean (RAM) will be computed as dependent variables. The dorsal neck muscle on the left side of the body was analyzed to determine the difference in sitting criteria between the two set styles. The two electrodes were connected to the body on the opposite side of the face to eliminate the signal interference caused by hand-arm device motions. The experimental conditions were presented so that the participants were randomized to minimize the possibility of order effects due to the repeated-measures nature of the experimental design.

2.2.2.3 *Subjective assessments*

After each photography day, participants completed a survey that included questions about body part discomfort, headaches, visual discomfort, rest breaks frequency, and workstation preferences. Participants will use the Borg CR scale [16] to characterize body parts and headache pain at the end of the workday, as shown in Figure 3. In addition, each of the seven signs will signify the presence or absence of visual discomfort (burning, itching, aching, watering, blurring, tired, or dry).

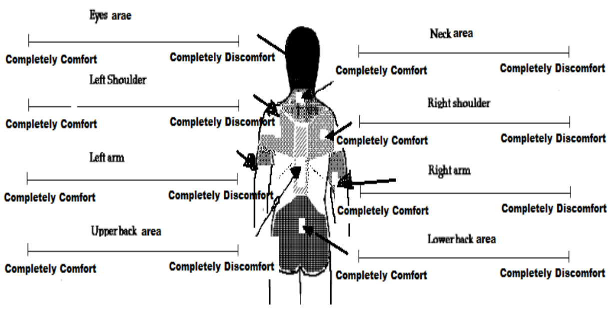

Fig.3 Visual analogue discomfort scale rated from `no pain to `extreme pain in 8 body areas

2.2.3 *Independent Variables*

A horizontal surface table and an adjustable inclined surface table were employed. Both tables are commercial well-known in the local market, as shown in Figure 4.

Fig 4. Some frames are used in different surface table types.

2.3 Apparatus

The equipment that was used to perform this experiment were:

1) A horizontal surface table and an adjustable inclined surface table.
2) Digital camera (Canon EOS 4000D DSLR, Germany).
3) Digital timer (Marathon TI080006-BK Digital Big Digits).
4) Electromyography (EMG) system (CASSY Lab., Leybold Didactic Gmbh, Germany).

2.4 Experimental Design and Procedures

Five adhesive markers were mounted on the skin of the right ankle, knee, shoulder, elbow, and wrist joints, as well as one marker at the hip joint to determine posture. The positions of joints in different anatomical regions were estimated using these markers. Articulation is determined by the angles of the lines that connect them. For example, the angle between the hip/trunk line and a line drawn from the trunk through the subject's eyes is used to approximate neck flexion. Additionally, surface electrodes were mounted on the subject's lower back and neck, just above the muscle. The EMG technique will be used to determine the relationship between the forces exerted by a muscle and its electrical activity. The participants' postures were captured using a digital camera.

The chair height must be adjusted so that the desk and sitting elbow lengths are approximately the same. At the end of the experiment, participants rated each workspace on a seven-point discomfort scale in which a score of 1, 3, 5, and 7 associated with completely comfortable, quite comfortable, just noticeable discomfort, and entirely discomfort, respectively. It is felt that the modifying body part discomfort would provide more acceptable discrimination than that obtaining by having subjects choose a number between one and seven and placing that number on the picture body part in discomfort. The reading of EMG was recorded and analyzed.

3. Results

3.1 Biomechanical Analysis

3.1.1 *Estimated Erector-Spinae Muscle Force*

The erector-spinae muscle forces were computed based on the average values of each forty-five working minutes. In addition, the average back muscle forces for a complete duration were employed for the statistical analysis. There was a significant difference between the horizontal and inclined table, $F(1,7)=81.793$, $p<0.000$. As shown in Figure 5, there was more significantly biomechanical stress when participants worked on the horizontal table (840N) than on the inclined table (705N).

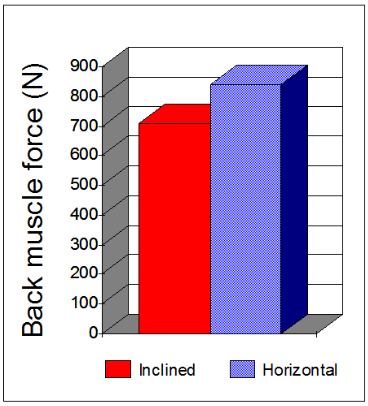

Fig.5. Effect of the table types on estimated erector-spinae muscle force.

3.1.2 *Estimated Compression Force acting at L5/S1*

The estimated compression forces acting at L5/S1 were computed based on the average values of each forty-five working minutes, and it was employed for the statistical analysis. There was significant differences between the horizontal and inclined table, F(1,7) = 19.495, $p<0.003$. As shown in Figure 6 there was more significantly biomechanical stress at working on the horizontal table (1250N) compared to working on the inclined table (1080N).

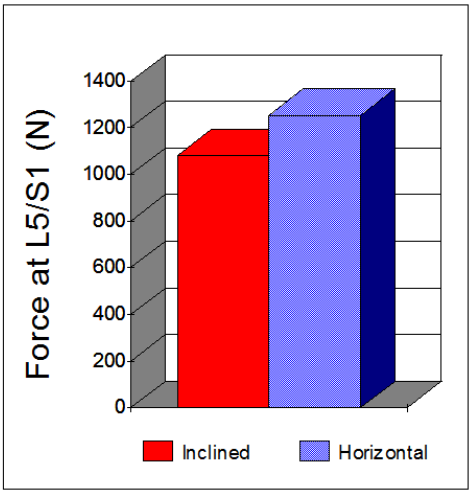

Fig.6. Effect of the table types on compression force acting at L5/S1

3.2 Results of EMG

There are two types of data (e.g., the mean and root-mean-square values). The average of neck muscle showed that there were significant differences between the horizontal and inclined table, for the mean values F (1,7) = 29.726, $p<0.001$, as well as for root-mean-square value F(1,7) = 18.099, $p<0.004$. As shown in Figure 7 there were more significantly muscular stresses at working on a horizontal table compared to working on the inclined table.

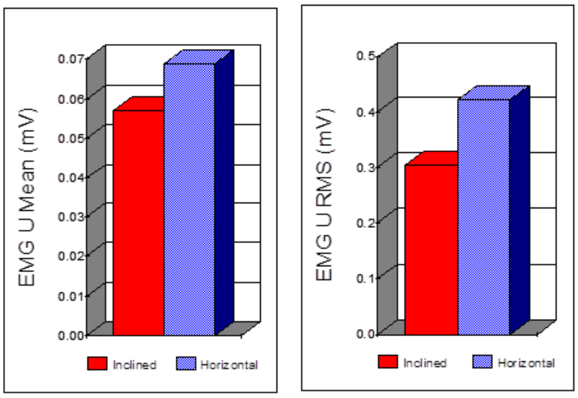

Fig.7. Effect of table types on neck muscular activities using EMG values.

3.3 Subjective Assessments

Each discomfort measure of the neck, right shoulder, left shoulder, right arm, left arm, upper back, and lower back for each subjective was computed based on the average values for a complete forty-five minutes period. Those values were employed for the statistical analysis. There were significant differences between the horizontal and inclined table as shown in Figure 8:

The neck muscle: F (1,7) = 1519.298, $p<0.000$

The right shoulder muscle: F (1,7) = 31.047, $p<0.001$

The left shoulder muscle: F (1,7) = 6.250E-04, $p<0.001$

The right arm muscle: F (1,7) = 5.760, $p<0.000$

The lower back muscle: F (1,7) = 5.130, $p<0.000$

As shown in Figure 8, there were more significant stresses at working on a horizontal table compared to working on an inclined table in terms of discomfort measures. Also, there were no significant differences between horizontal and inclined tables on the discomfort scale at the lift arm muscle and the upper back muscle.

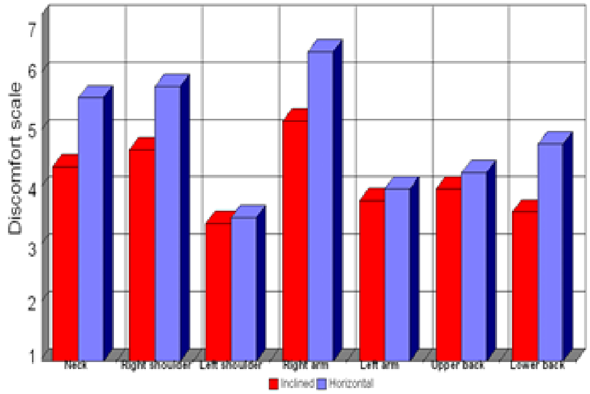

Fig.8. Effect of table types on neck, right shoulder, lift shoulder, right arm, lift arm, upper back and lower back discomfort scales.

4. Discussions and Conclusions

Using biomechanical models to predict musculoskeletal stresses is one of the best and most practical methods used by task designers and medical professionals. A biomechanical model's efficacy is contingent upon its ability to capture the human body's complex features accurately. The proposed model showed its capability for evaluating stresses imposed on the participants' backs in the furniture application. This evaluation was similar to the model used in Khalil and Ramadan [10] for assessing manual lifting tasks. The majority of these models examine the stresses imposed on the human body when it is in a static position. Just a few employ dynamic analysis of the body's motion trajectory. Dynamic analysis is far more complex and time-consuming than static analysis and as the number of links in the model rises, the computational complexity increases exponentially. It should be noted that using biomechanical models to assess musculoskeletal system stresses has both advantages and disadvantages.

Among the benefits is collecting objective data on the forces and torques applied to different joints, bones, and muscles without resorting to often dangerous and psychologically inappropriate invasive techniques. Consequently, when interpreting the findings, one should be thoroughly familiar with the model's assumptions and limitations. Another common occurrence is the absence of reliable in vivo data on the stress limits of soft and hard human tissues. Again, considerable judgment should be exercised in interpreting model output data. However, the model outputs can also provide a handy approximation of otherwise unavailable stress values. These principles can be used in combination with work analysis and design guidelines.

Microcomputers' widespread usage in recent years enables analysts to more openly using complex biomechanical models to investigate the relationship between posture, task type, and stresses placed on different joints and muscles of the human body. The model established in this article views the human body as an eight-link structure. It differs from more simplistic biomechanical models in that it considers the hip stress as distinct from the L5/S1 stress by separating the two articulation points.

The findings of this study showed that students who used an adjustable inclined surface table experienced less biomechanical tension and a more relaxed posture than students who used a horizontal surface table. The adjustable inclined surface table did also maintain a stress-free position for the muscle system. The study was conducted using a biomechanical model to manage both static and dynamic modes to predict musculoskeletal stresses. Additionally, the study was accompanied by the use of EMG to assess neck muscle tension and by the psychophysical measure of comfort. As a result, the drafting table must be revamped to accommodate versatility. Mobility here refers to adjusting the table height and angle of the surface to stand or sit more upright and with less neck flexion.

Additionally, the study established that the current horizontal table compelled students to lean forward and that prolonged trunk effort resulted in complete muscle fatigue. This result is consistent with the findings of other researchers who assessed the use of furniture using various posture assessment techniques [17, 18]. Additional research on sloping furniture may benefit from factoring out visual and anatomical determinants of posture and attempting to define and evaluate complex changes in posture.

The evidence from the agreement of biomechanical stress measures, EMG values, and psychophysical comfort scales proved the capability of the new available approaches. As a result, the findings in this study demonstrate the efficacy of a methodology that utilizes a body posture recording and analysis technique while the subject is working. The versatility of this methodology enables the designer to use the model in both field and laboratory studies. Additionally, the model overcomes the limitations of previous methodologies by incorporating the postures' time histories and the dynamic model of the entire movement.

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