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Measurement of postural angles during work

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A method for continuous measurement of postural angles (head angle, arm abduction, arm flexion and back angle) is described. The method involves attachment of potentiometer pendulums at the head, shoulder and back. In laboratory tests the equipment ('Physiometer') seems to record the actual body angles adequately. The system is relatively simple and robust and well suited for field studies.

It is planned to use the technique of postural angle measurements in the assessment of workload. In such measurements several limitations must be considered. These include the support of the body by the elbows and the carriage of load in the hands. Both influence muscular load although the angle may be unchanged.

1. Introduction

The need to improve work posture has been documented in a number of studies which have shown a relation between stressful postures at work and functional disturbance or pain in various parts of the musculo-skeletal system (Maeda *et al.* 1980, Stubbs 1980, Andersson 1984, Westgaard and Aarås 1984, 1985). In such studies the assessment of workload may be performed by measurement of electromyography (EMG) from selected muscle groups (eg. Aarås and Westgaard 1987), or by recording postures and body motion at the workplace (Karhu *et al.* 1977, Karhu *et al.* 1981, Corlett *et al.* 1979, Corlett and Manenica 1980, Hünting *et al.* 1980, Persson and Kilbom 1983).

In biomechanics, quantitative models for estimation of segmental work load can be designed on the basis of body segment motions and the muscle actions responsible for these motions. In these models the human body is decomposed into a set of articulated links in a kinetic chain. When resulting load moments are calculated at distinct articulations, postural angle measurements are necessary. The frequency distribution of angles of the neck, back, elbow and hands during work may be measured manually (Grandjean *et al.* 1982, Maeda *et al.* 1980). More sophisticated systems for three-dimensional automated tracking on a large number of motion segments have recently been developed (Samuelson *et al.* 1987).

To perform *continuous* measurements of postural angles, we constructed a device ('Physiometer') based on potentiometer-sensed pendulums attached to the upper arm

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(flexion and abduction of the gleno-humeral joint), the head and the back. This paper presents the methodology and testing of the equipment.

2. Design philosophy

The development of this equipment was based on the following criteria:

—The method had to be cheap, easy applicable and suited for continuous use.

—The equipment should record accurately the movements undertaken by the subjects during work.

—The measurements had to be repeatable under predescribed conditions, i.e. within the range of movements normally occurring in the actual work situation.

—The recording equipment should not interfere with the movements being recorded.

—The following angles were to be recorded: Head, neck, back, upper arm flexion and upper arm abduction angles.

3. Technical description

The angle transducer consisted of a pendulum potentiometer (figure 1). This method was chosen because of its simplicity. Potentiometers with low rotational friction were essential to achieve tolerable mechanical hysteresis, which is especially important when slow movements are recorded.

3.1. *Electronic circuits*

The electronic circuits for determining the head, back and arm angles are shown in figure 2. The RC-circuit between IC1 and IC2 set the time constant to about 0·2 s in order to reduce the effect of pendulum overshoot and afterswing during staccato movements.

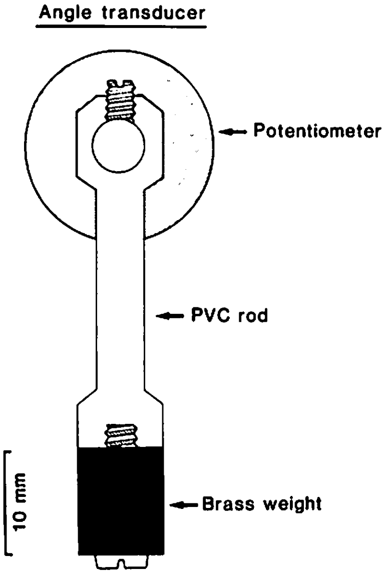

Figure 1. Schematic illustration of the potentiometer pendulum transducer. A standard Spectrol Model 157 potentiometer with a pendulum attached to the axis was used. In later versions, ball bearings were applied to reduce the rotational friction.

The calibration circuit was included for easy electrical calibration of the 'Physiometer'. The calibration steps are signals analogous to 0, 45 and 90 degrees of deflection.

Beside outputs from all channels to a tape recorder/linear recorder, head and back circuits were also connected to a neck angle calculating circuit (figure 3). In this circuit, neck angle is calculated as the difference between head and back angles at IC1. The inputs to IC1 are damped, and as a result the time constant of the neck angle recording is approximately 0·3 s.

All channels have buffered (IC5) gain-controlled outputs, as well as analogue displays.

3.2. *Zero calibration*

The potentiometer for measuring head movements was mounted in a head-phone set (figure 4). Other potentiometers were fixed properly to the body by attachment plates for the upper arm and back. They were made rotatable for determining the zero set-point after body zero position had been defined.

3.3. *Definition of body reference position*

To make reproducible measurements a body position has to be defined at which the postural angles are set to zero degrees. A well-balanced upright position with relaxed shoulders and the upper arm hanging relaxed along the body was chosen as the zero position. In this position the influence of the gravity forces on the musculo-skeletal system are minimal.

Definition of zero head angle required special attention, and was performed by sight line fixation. Because sharp vision is limited to a very small area of the retina it is possible to define the relationship between the eye itself and the line of sight. In the resting eye position all external eye muscles are at equal tension. Static muscle stress

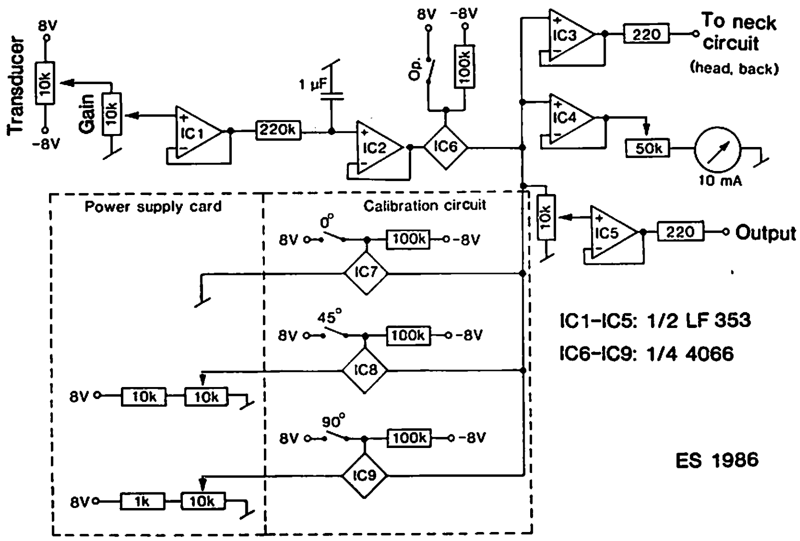

Figure 2. Circuit diagram of the 'Physiometer' for head, arm and back angles. An electric calibration circuit is shown within the interrupted lines. The RC-circuit between IC1 and IC2 sets the time constant to about 0·2 s.

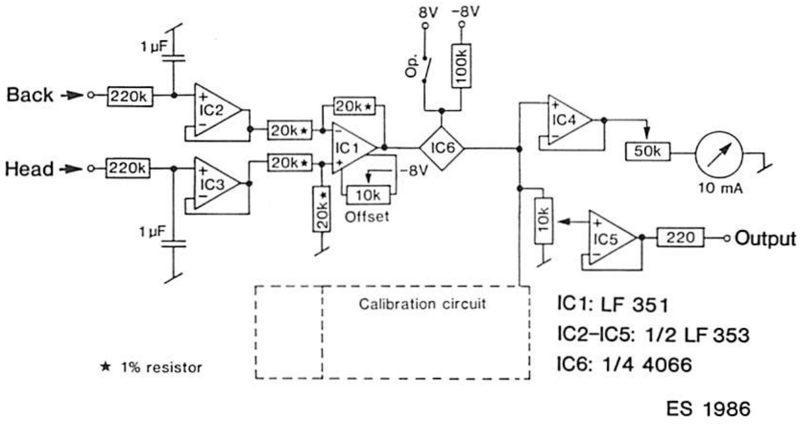

Figure 3. Circuit diagram for continuous calculation of the neck angle from the head and back angles. The calibration circuit is identical to the one shown in figure 2.

occurs in these muscles when the sight line deviates from the resting position, and the head will alter position in relation to the sight line to lower this stress.

The reproducibility of head positioning was tested in nine subjects by intermittent fixation of the eyes on a red spot on a white background at eye height 5 m in front of the subjects. The fixation period was approximately 10 s. Between these periods the subjects turned their heads away. The result of these experiments is shown in figure 5. The mean difference between the recordings for each subject ranged between 0·57 and 1·13°, with an average of 0·85°. It was therefore concluded that defining of zero head angle by the sight line technique was a reproducible and fully acceptable method.

The reproducibility of the arm zero value was tested similarly in a group of five subjects. For each subjects the upper arm was kept passively dependent ten times, and the angle recorded. The mean deviation from the mid-point for each subject ranged

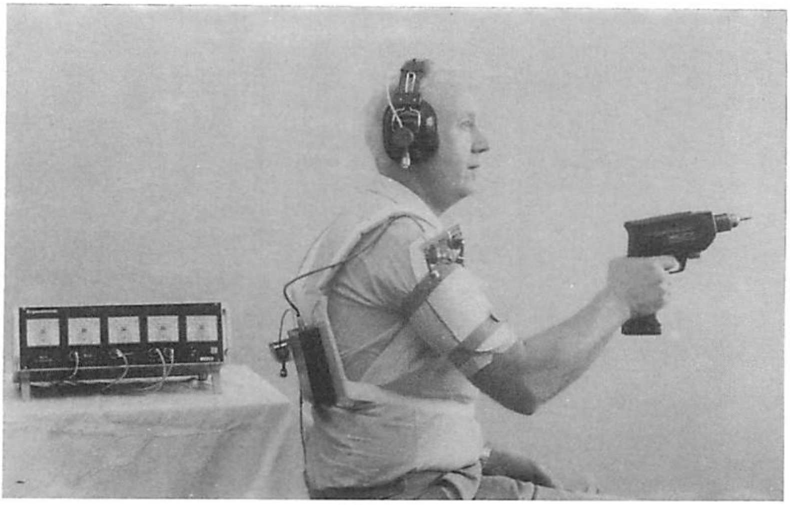

Figure 4. The 'Physiometer' with angle transducers attached to the head, shoulder (arm flexion and arm abduction) and back. The neck angle is continuously calculated as the difference between head and back angles.

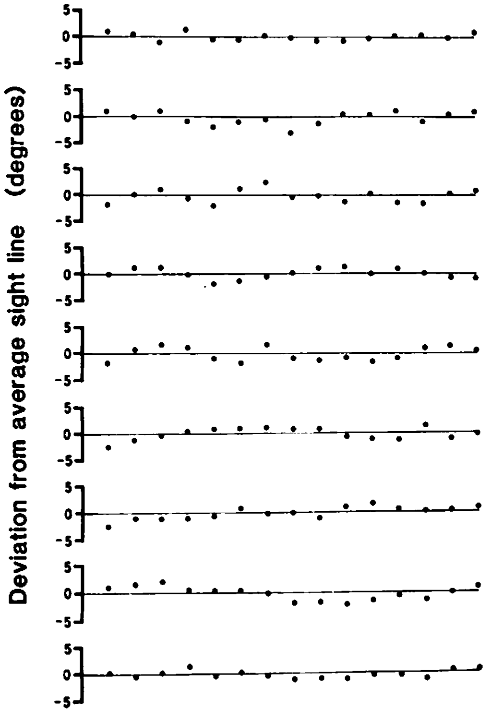

Figure 5. Test procedure for defining head zero value by the sight line technique in nine subjects who intermittently fixated the eyes for periods of 10 s on a red spot at eye height at a distance of 5 m. Between these periods the subjects turned their heads away.

between 0·4 and 2·1° with an average of 1·2° for flexion, and between 0·3 and 1·6° with an average of 0·9° for abduction.

In later recordings, all angles were set at zero before measurements of the working posture, and the zero values were checked after each recording period.

3.4. *Physiological assessment of the 'Physiometer'*

3.4.1. In vitro *assessment*

To compare the recorded angle with the real one, we used a calibration set-up as shown in figure 6. This test was performed to determine the error produced by the hysteresis of the pendulum potentiometer and the electronic damping of the signal. The calibration set-up was designed to mimic the single plane movement (flexion) of the gleno–humeral joint. A potentiometer (P1) was fastened to a ruler-like arm to give the exact movement of the arm. About 10 cm along the arm one of the pendulum potentiometers (P2) was attached. This distance was approximately the same as the distance from the gleno–humeral joint to the 'flexion' potentiometer. In this calibration set-up, P2-output (before 'Physiometer' damping) was also recorded. The arm was then manually given movements similar to arm movements in the gleno–humeral joint used by workers at an electromechnical assembly plant.

Figure 6(*a*) shows true movement (P1), pendulum potentiometer recorded movement (P2) and 'Physiometer' output for a 40° oscillatory movement at a frequency of about 0·25 Hz, followed by a step-like movement from a low to a high position at the

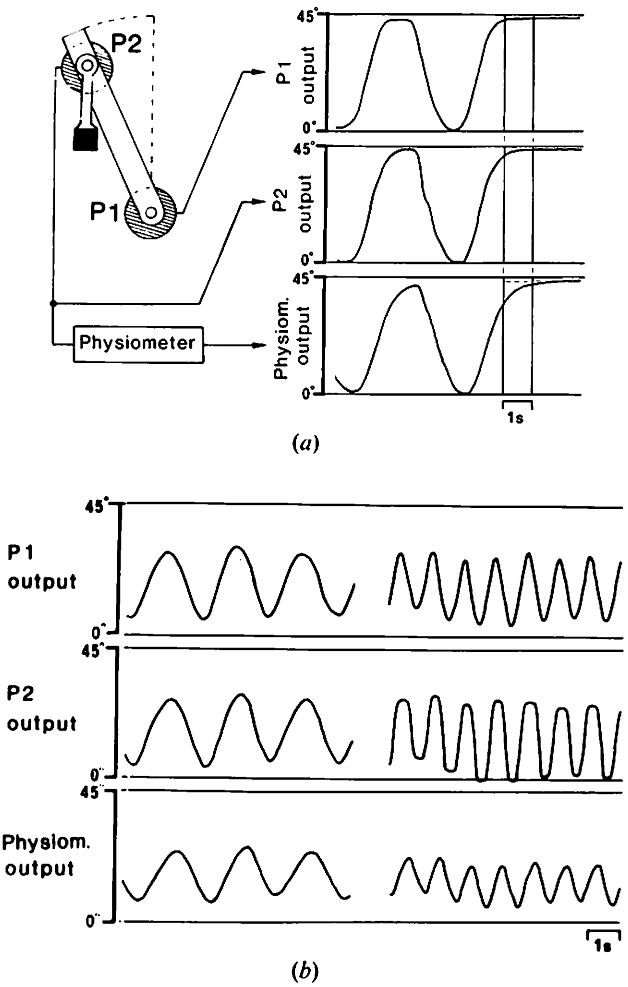

Figure 6. *In vitro* test set-up for determination of the pendulum transducer characteristics (P2 output) and output from the 'Physiometer' (Physiom. output) compared to true angular movement of the transducer (P1 output). (*a*) A stepwise movement indicates the time delay of the 'Physiometer' caused by the inherent electronic time constant of about 0·2 s. (*b*), Oscillatory movements at a frequency of about 0·5 and 1 Hz (angular velocity of 21 and 34 °/s). This indicates considerable damping of the 'Physiometer' output compared to P1 output at higher frequencies. However, such fast movements are rare in occupational work situations.

same frequency. This mimics an arm movement in the gleno-humeral joint at moderate to low speed, and it is seen that the P2 pendulum and the 'Physiometer' record the movement with reasonable accuracy. At the final stepwise movement the 'Physiometer' under-represents the angle by about 5° of the first 0·5 s after reaching the plateau, and by 1·5° the next 0·5 s. Much faster stepwise movements (within the range most likely to occur in occupational work situations) are still represented by an angle not deviating by more than 5° from the correct value within 0·5 to 1 s after reaching a plateau. Most actual work tasks in our study comprised movements with angular plateaux of some duration (picking electronic components from component bins, inserting the components into electronic circuit boards, performing wire wrapping etc.), where the movement was halted for some period of time. Thus sufficient time is given for the 'Physiometer' output to approximate the real deflection.

Figure 6(*b*) demonstrates results for oscillatory movements at a frequency of about 0·5 and 1 Hz (angular velocity 21 and 34 °/s). At 0·5, the P2 and 'Physiometer' outputs describe the true movement reasonably accurately, but with a slight phase lag and with a 29% reduction in peak-to-peak amplitude of the 'Physiometer' output because of electronic damping. At 1 Hz the oscillation is approximating the resonance frequency of the P2 pendulum and the P2 amplitude is about 8% higher than the real movement (P1). However, the electronic damping ensures that the output from the 'Physiometer' is reduced by 38% relative to P1 amplitude. Thus, the 'Physiometer' is clearly not suited to recording fast oscillatory movements. However, these are rarely required in occupational work situations. Fast oscillatory movements of body structures such as lower arms, hands and fingers are often observed in occupational settings (i.e. typing), but upper arms and trunk then remain relatively stable. The performance of the 'Physiometer' is also reflected in the quantification of the signal which in our analyses is performed by averaging the signal over 0·5 or 1 s interval (Aarås *et al.* 1988).

The 'Physiometer' was found to perform to the same standard at low-amplitude deflection. Sometimes the pendulum would perform a staccato movement, but this was always smoothed by the electronic damping of the 'Physiometer'. Slow test movements were performed to further indicate the mechanical hysteresis of the pendulum potentiometer. As shown in figure 7, the three output curves coincide well in all phases of the movement, but with the postural angle under-represented by about 3° during the dynamic movements.

3.4.2. *In vivo assessment*

In another test procedure, the 'Physiometer' output during the simulated ordinary work task was compared with video recording of the movements. Flexion of the shoulder joint was chosen for the study. The video camera was directed perpendicular to the plane of movement, i.e. approximately the sagittal plane. The subject was seated and performed flexion of the shoulder joint by picking components from a component bin which necessitated a flexion angle of about 50° and assembled the parts on a table with a flexion angle close to zero. The two turning points for 15 consecutive flexions showed a range of 47–57° and 0–7°, respectively. The upper arm angle relative to the vertical was measured on the video screen by a goniometer.

From these 15 consecutive movements, the difference between the video-recorded angle and the corresponding angle derived from the 'Physiometer' at the top turning point ranged between −2 and +3°, with a mean of +0·6°. The difference between the low turning point angles ranged between 0 and +2°, with a mean of +0·7°. These recordings indicated that on average the 'Physiometer' underestimated slightly the angle of the real movements.

4. Discussion

The 'Physiometer' seems to describe the postural angles of upper arm, head, back and neck adequately. The system is relatively simple and robust and thus well suited for field studies. The design philosophy criteria were fulfilled concerning comfort in use, and the even during several hours recording the 'Physiometer' did not interfere with the work task itself.

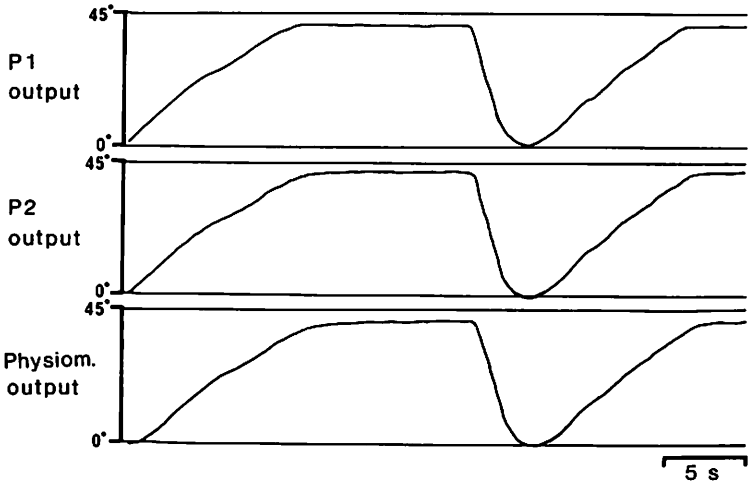

Figure 7. *In vitro* test set-up similar to that in figure 6 for very slow movements for testing of transducer hysteresis because of internal rotational friction. Note the good correlation between the outputs. These are angular movements frequently seen at the back.

The small variation in head angle when the subjects repetitively looked at a fixed spot (figure 5) confirms that resting eye position is limited to a small area in the retina. Therefore the method of eye fixation is acceptable when defining zero head angle and checking the zero position after use of the 'Physiometer'.

The angle transducer consists of a pendulum potentiometer. In this technique, the friction force (mechanical hysteresis) on the potentiometer axis may present a source of error, especially in small smooth movements. In staccato movements, the pendulum will eventually oscillate into the near-vertical position. Although we chose potentiometers with low rotational friction, the viscosity of the potentiometer axis lubricant increased somewhat during the 15 months it was used. Therefore the transducers were improved by applying ball bearings at the axis. Nevertheless, the change in friction was moderate, and the test for hysteresis presented in this study was performed after application series at the workplaces (Aarås *et al.* 1988).

With the present technique with pendulums the deflection of the body parts are referred to with respect to the vertical and not to the main trunk position. For example, when bending the upper body forward while maintaining the upper arm in a fixed position relative to the horizontal plane, the arm–trunk angle increases whereas 'Physiometer' arm flexion remains constant. This may seem a source of error. However, postural angle measurements are especially useful if the recordings provide estimates of load on the musculo-skeletal system. Muscle load is primarily dependent on the orientation of body structures in the gravitational field. This is in fact the parameter measured by this pendulum potentiometer technique.

When postural angle measurements are used to assess workload, several limitations must be considered:

—Supporting the elevated arms reduces the muscle load in the shoulder area. Chaffin (1973) showed that an elbow support reduced the load moment on the shoulders.

—Loads in the hands (tools, components) increase the muscular load although the angle may be unchanged.
—Angular velocity is also important when assessing workload (Leskinen 1983).

In conclusion, measurement of postural angles with a pendulum potentiometer method seems to be acceptable both in terms of accuracy and repeatability. When angle measurements are used in assessing workload, however, the limitations listed above should be considered.

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On décrit une technique pour l'enregistrement en continu des angles posturaux (angle de la tête, abduction du bras, flexion du bras et angle lombaire). Cette technique utilise des pendules potentiométriques fixés à la tête, à l'épaule et au dos ('Physiomètre'). Cet équipement, testé en laboratoire, donne des résultats satisfaisants. Il est relativement simple et robuste et convient bien à des études sur le terrain. On envisage d'appliquer cette technique de mesure des angles posturaux à l'évaluation des charges de travail. Mais il faut également tenir compte de certaines de ses limitations, en particulier lorsque le corps s'appuie sur les coudes ou lors du transport manuel de charges. Ces deux modalités influencent la charge musculaire, bien que l'angle reste inchangé.

Eine Methode für die kontinuierliche Messung, der bei Körperhaltungen auftretenden Winkel (Kopfneigung, Armabduktion, Armbeugung und Rückenneigung) wird beschrieben. Die Methode umfaßt das Befestigen von Potentiometer 'Pendulums' am Kopf, Schulter und Rücken. In Labortests scheint die Ausrüstung die aktuellen Körperwinkel hinreichend Aufzuzeichnen. Das System ist relativ einfach und robust und eignet sich gut für Felduntersuchungen.

Es ist geplant, diese Technik zur Messung der Winkel bei eingenommenen Körperstellungen zur Bewertung der Arbeitsbelastung zu benutzen. Bei solchen Messungen müssen einige Beschränkungen beachtet werden. Diese beinhalten di Unterstützung des Körpers durch die Ellenbogen und das Transportieren von Lasten in den Händen. Beides beeinflußt die muskuläre Belastung, obwohol der Winkel unverändert geblieben sein kann.

姿勢角度（頭角度，腕外転，腕屈曲，背角度）の連続測定方法を述べる。本方法では頭，肩，背中に電位差計振子を取り付ける。実験室試験で本装置（Physiometer）は実際の身体角度を適切に記録するように思える。本システムは比較的簡単，頑強で現場研究に好適である。

本姿勢角度測定法を作業負担の評価に使用する予定である。そのような測定ではいくつかの制限を考慮しなければならない。それには肘による体の支えと手での荷物の運びがある。角度が不変であるかも知れないが，両方とも筋負担に影響を及ぼす。