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## **A contribution to the technique of recording of the E. C. G. and heart rate in physiology of work and sport**

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During the recording of the bioelectrical potentials in the investigations of the physiology of work and of sport there occur many artefacts, that make sometimes the evaluation of the records difficult or even impossible. One part of these artefacts is of biological origin (i.e. the electrical activity of other organs than the examined one), another part of the artefacts arises from the movements of the electrodes, from electrolytic processes on their surface, from external electromagnetic fields (e.g. from the mains supply, from sparkling), etc. A very troublesome artefact that is often observed in the examinations of work physiology arises, when the subject touches a metallic component (e.g. the framework of a machine) which is connected with ground or with the grounded main lead.

Many of these artefacts may be considerably reduced by lowering of the electrode resistance, by use of a convenient electrode material and by an appropriate fixation of the electrodes. Electrodes for studying bioelectrical potentials in work physiology and sport physiology are to be designed from this point of view. Moreover, it is necessary that the wearing of the electrodes even for a long time does not cause discomfort to the examined subject.

Electrocardiographic electrodes designed for registration during physical strain must be applied in a way that during the movements of the subject no shifting of the electrodes and no large change in the pressure of the electrodes against the skin arises. Near to the body region, where the electrodes are localized, there should be no large active muscle group. Artefacts, caused by skin potentials and by sweating, may be greatly reduced by lowering of the electrode resistance. In general, electrodes, localized near to the heart, are more suitable, because heart action potentials of larger amplitude are led off from them.

Sometimes it is impossible to record a distortion-free electrocardiogram during physical strain at all, although all the mentioned precautions have been

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taken. This may occur also in relatively quiet subjects, working in strong electromagnetic fields: near the electrically driven machines, etc. In this case it is, however, often possible to record at least the heart rate and the pulse intervals, when the bioelectric potentials are amplified by a differential-input preamplifier and passed by a band-pass filter. This problem was thoroughly investigated by *Penáz* (1960), who has shown, that when a simple resonant circuit is used, the most adequate resonant frequency for the electrocardiogram of an adult human is 20–25 c/s. This resonant frequency is larger than the main frequency components of the movement and sweating artefacts and lower than the interference from the mains supply and from the electromyogram. *Penáz* (1960) designed an automatic heart rate counter based on this principle.

In subjects, working on various machine-tools, the use of a single resonant circuit is not satisfactory for filtering out the 50 c/s interference. Decrease in the damping of the resonant circuit (i.e. increase in the value  $Q$ ) may not be an adequate solution of this problem: the slowly decaying oscillations, arising in the resonant circuit after passing of the complex QRS, make the precise determination of the moment of the QRS complex impossible.

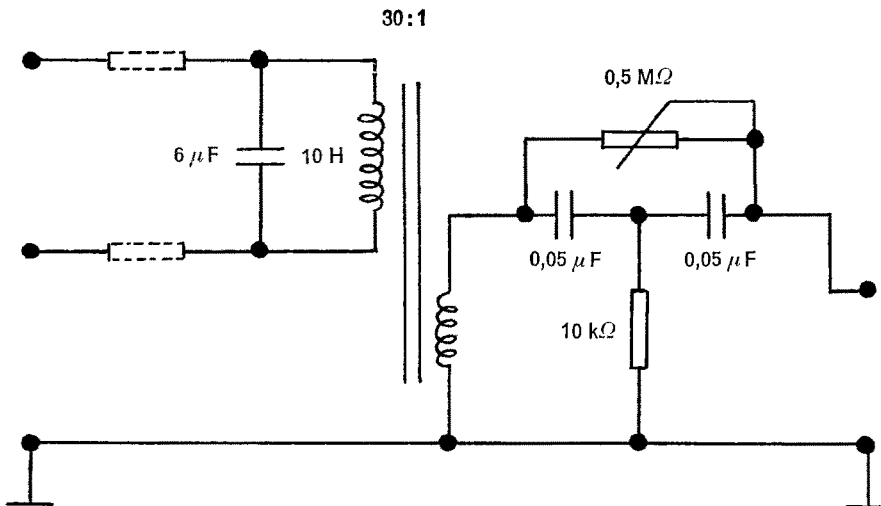


Figure 1 *Diagram of the band-pass filter.* Resistors drawn by interrupted lines (at least 20 kilohms) may be omitted, if the output resistance of the preamplifier is sufficiently large. Potentiometer 500 kilohms is adjusted for maximal 50 c/s rejection.

We have therefore combined a resonant circuit (frequency of resonance approximately 20 c/s) with a bridged-T circuit (frequency of maximal attenuation equal to the frequency of the mains, i.e. 50 c/s) (Figure 1). The filter is connected to the output of a standard symmetrical differential-input preamplifier of bio-electrical potentials. The frequency 50 c/s and larger frequencies are attenuated by this simple filter at least fifty times with respect to the frequency 20 c/s.



Figure 2

*Examples of the recording of E.C.G. and heart rate. Adult healthy male, chest electrodes. A: E.C.G. B: E.C.G. potential after passing the band-pass filter. Upper records: squatting. Lower records: soldering with an electrically heated solder-iron.*

A typical record is shown in Figure 2: the E.C.G. led off from the chest electrodes, described below in this paper, and the same potential passed through the band-pass filter, are compared. By passing through the filter the E.C.G. potential is transformed into damped oscillations, coincident with the complexes QRS. The wave T, the movement artefacts and the electromyographic potentials disappear from the record, the 50 c/s interference is very greatly reduced.

In some of our investigations the signal from the output of the filter was led to the input of a small magnetic tape recorder (speed of the magnetic tape 19 cm = 7.5" per sec.).<sup>1</sup> This arrangement minimalizes the weight of the instruments to be transferred for use of this method in field research. The evaluation of the record, counting of the heart rate and the pulse intervals or other automatic analysis may be then performed subsequently in the laboratory.

When the E.C.G. is to be recorded during work, the standard electrocardiographic electrodes and derivations often may not be used. Because, however, most attention in the analysis of the E.C.G., recorded during work, is given to the time relations of the respective waveforms (P-Q, R-R, Q-R-S, Q-T, etc.), also non-standard E.C.G. derivations may yield useful information. We have therefore designed and proved two types of electrocardiographic electrodes for recording during physical strain and near the electrically driven machines. The

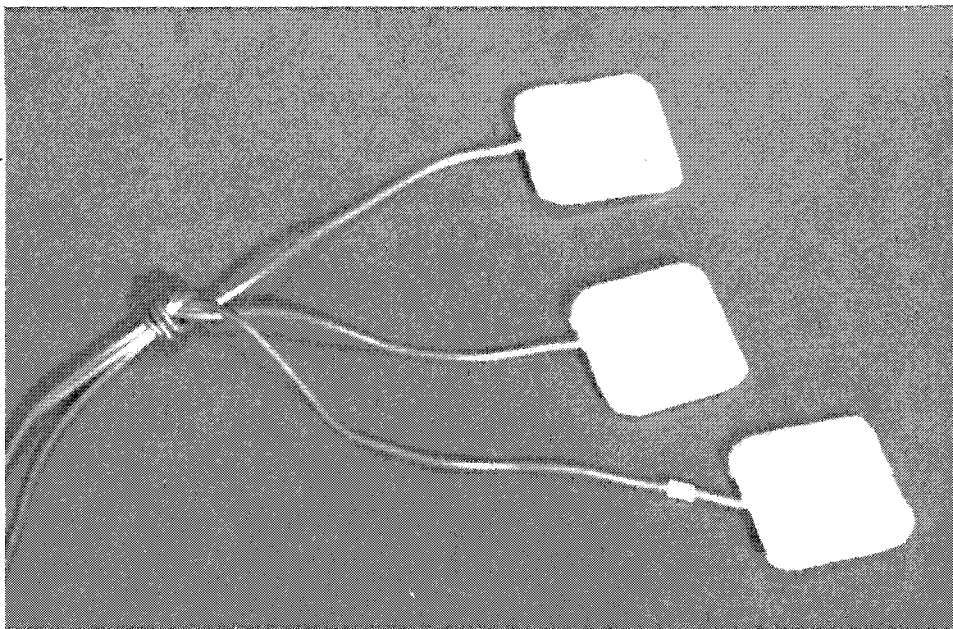


Figure 3 Chest electrodes for recording of the E.C.G. and heart rate during work.

<sup>1</sup> The schematic diagram of the arrangement for the "direct recording" on the magnetic tape was presented in Figure 1 of a previous paper (Mikiska 1962).

first type – chest electrodes – was proposed for use in subjects performing large movements of the whole body, walking to and fro during work etc. The second type may be suitable for recording of the heart rate in subjects sitting at their work.

The chest electrodes for recording of E.C.G. during work are demonstrated in Figure 3. They are made of copper plates of rectangular shape ( $5 \times 5$  cm, i.e.  $2 \times 2$ " ). Flexible cables are soldered to the plates; the area of the junction is to be covered thoroughly by a layer of insulating coating (to prevent electrolytic potentials to arise). The copper plates are then enveloped in several layers of flannel or gauze which are wetted before application of the electrodes by the 5% solution of sodium chloride. The electrodes are localized in the following way: One exploring electrode is applied over the apex cordis (i.e. in the medio-clavicular line in the 5th intervertebral space): care should be taken of the correct position of this electrode, because any deviation, especially to the right side, decreases the voltage of the wave R led off from this electrode. The other exploring electrode is applied in the right anterior axillary line in the 5th intervertebral space: the position of this electrode is, however, not critical. A third, grounding electrode is applied in the right medioclavicular line in the 5th intervertebral space: the localisation of the grounding electrode is, as is obvious, also not critical.

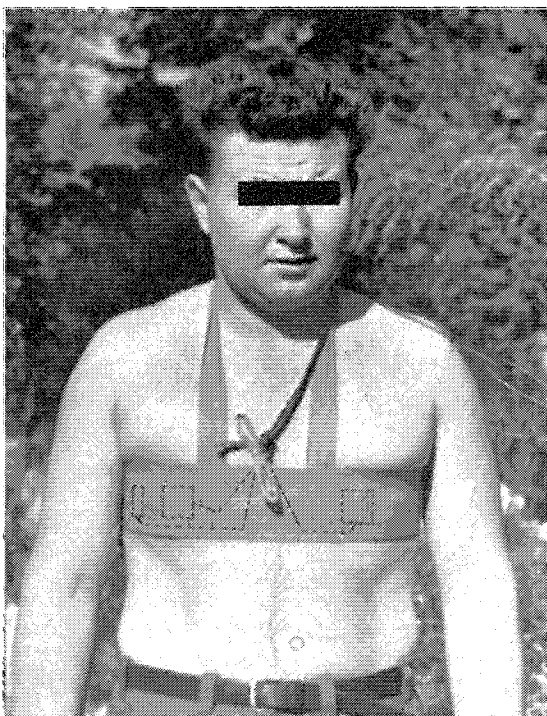


Figure 4 Localisation and fixation of the chest electrodes.

The electrodes are fixed in male subjects by means of a broad (10 cm = 4" approximately) rubber band; it is convenient to fix the cables of the electrodes by tying them by special tapes to the rubber band, to prevent shifting of the electrodes when the cables are pulled by. The localisation of the electrodes and their fixation are shown in Figure 4. – The electrodes are applied in the following way: At first the rubber band is laid on, then the electrodes (wetted in saline solution) are inserted beneath it and the cables are tied to the rubber band. Last the subject puts on his dress over the applied electrodes. – In female subjects usually the electrodes may be satisfactorily fixed by the underwear or by the sport dress, so that further fixation is not necessary.

The electrocardiogram recorded from these chest electrodes is very similar to the derivation  $V_4R$ , because the potential of the right exploring electrode does not differ much from that of the right arm. A less complete similarity may be mentioned between this derivation and the standard derivation I. – The resistance between the leads of any two of the applied electrodes does not usually exceed 5000–6000 ohms, although no procedure for lowering the skin resistance is performed.

The use of the described chest electrodes has enabled us to record the electrocardiogram during sitting, quiet and deep breathing, standing and even during quiet walking. The heart rate and the pulse intervals (with the use of the above mentioned band-passfilter) could be recorded during many kinds of physical exercising (running, squatting, working on an ergometer, etc.), in workers operating the lathe, the electrical drilling machine, the spot-welding machine, the panels of telautomatics etc.

In our examinations the subjects have worn the electrodes for 4–6 hours without complaining of any discomfort. It was so possible to record the heart rate at a distance at any moment without disturbing the subject in his work.

Another localisation of electrocardiographic electrodes could be used in subjects sitting at their work. The electrodes are made of the same material: one exploring electrode is applied on the forehead, the other exploring electrode on the left leg, the grounding electrode on the right leg. All electrodes are fixed by broad rubber bands. The electrocardiogram recorded from these electrodes is similar to the standard derivation aVF, its voltage is, however, larger than that of the mentioned standard derivation. – This localisation of electrodes is suitable only for examinations lasting a shorter time: some subjects feel a discomfort after application of the electrode on the forehead lasting more than 45–90 min.

We have used this localisation of electrodes (forehead-left leg) only for recording of the heart rate, because the voltage of this E.C.G. derivation is smaller and the electromyographic potentials larger than those recorded from the chest electrodes. Reliable continuous recording of the heart rate was, how-

ever, possible from this localisation of electrodes during many working activities, e.g. during type-writing, during soldering with an electrically heated solderiron, during performing psychological tests, etc.

#### *Literature*

*Mikiska A.*: In print, 1962.

*Penáz J.*: Scripta medica (Brno), 1960, 33, No. 1-2.

#### *Summary*

In physiological research the continuous recording of the E.C.G. or at least of the heart rate during work or physical exercise is sometimes desirable. Standard electrocardiographic electrodes and derivations are, however, often unsuitable: modified electrodes must therefore be used for the recording.

In the paper two types of such electrodes are described, which have been proved both in laboratory experiments and in field research. – The first type – special chest electrodes – may be worn by the subject under his usual dress for several hours without causing any discomfort. The second type – localisation forehead-left leg – is suitable for examinations of shorter duration in subjects sitting at their work. – When the artefacts make the evaluation of the E.C.G. waveforms impossible, it is still possible to registrate the heart rate and the pulse intervals by means of a band-pass filter. A simple filter for this aim, designed for connection to the output of a standard symmetrical differential-input preamplifier of bioelectrical potentials, is described.

*Beitrag zur Technik der Registration von E.K.G. und der Pulsfrequenz in der Arbeits- und Sportphysiologie*

#### *Zusammenfassung*

Bei den physiologischen Untersuchungen ist manchmal die dauernde Registration des Elektrokardiogrammes oder der Pulsfrequenz erforderlich. Elektrokardiographische Standard-Elektroden und Ableitungen sind oft ungeeignet, deswegen muß man besondere Elektroden für die Registration verwenden. Zwei Typen solcher Elektroden, welche in Laboratoriumsversuchen sowie im Betrieb geprüft wurden, werden beschrieben. Die erste Type – spezielle Brustelektroden – können von der Versuchsperson mehrere Stunden lang unter dem Kleide getragen werden, ohne einen Diskomfort hervorzurufen. Die zweite Type – Lokalisation Stirn – rechtes Bein – eignet sich für Untersuchungen kürzerer Dauer bei Versuchspersonen, die sitzende Arbeit haben. – Wenn Artefakte die Bewertung der E.K.G.-Wellenformen unmöglich machen, ist es doch möglich, die Pulsfrequenz und -intervalle mittels eines Band-pass-filters zu registrieren. Ein einfacher Filter für diesen Zweck, der für den Anschluß an einen symmetrischen Vorverstärker bioelektrischer Potentiale konstruiert wurde, ist beschrieben.