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EXERCISE ELECTROCARDIOGRAPHY IN VASCULAR LEG AMPUTEES AS A TOOL IN REHABILITATION

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Abstract

Thirty-nine subjects, mean age 67, range 43-92 years, with a leg amputation because of peripheral vascular disease were studied during prosthetic rehabilitation. They had a history and rest electrocardiogram (ECG) examination which revealed cardiac problems in more than half of the subjects. They performed a graded exercise ECG test within three weeks of starting the rehabilitation program. Their walking ability at the end of the program was classified and compared with the exercise test findings.

The test was performed on a specially designed arm ergometer permitting coordinated use of the arm and large trunk muscles. Cardiac condition was judged by the achieved peak heart rate (mean 124 ± 3.6 (SEM) beats per minute) and observed ECG abnormalities. ST-segment depressions of more than 0.1 mV were observed in fourteen subjects and aberrant beats in eight subjects. These exercise findings are in addition to the known cardiac problems. The mean peak work load obtained during exercise testing was 63 ± 3.4 (SEM) Watt. It was concluded from these results that the average cardiac and physical condition in vascular leg amputees is poor.

Only one of the five bilateral amputees included in the study became capable of prosthetic walking indoors with a walking frame. Of the thirty-four unilateral amputees all but two became able to walk with a prosthesis of whom twenty-one outdoors for more than 40 metres.

The unilateral subjects only capable of walking indoors revealed significantly lower mean values for both peak heart rate and peak work load than those walking outdoors.

Introduction.

Eighty to ninety percent of the some 2000 leg amputations performed annually in the Netherlands, are because of circulatory problems caused by peripheral atherosclerosis (15). Combined with the relatively high age of the patients with a vascular indicated leg amputation (50-90 years) this gives rise to the assumption that the cardiac condition is diminished in a significant number of these patients.

Despite this assumption quantitative data on the cardiac condition of this population is scarce. Influence of the cardiac condition on the rehabilitation was mentioned by Hamilton (11) and Peizer (14). However, to our knowledge only Kavanagh (12) re-

ported on the cardiac condition of a group of elderly Canadian amputees which he investigated by exercise testing.

It is important to detect subjects with a poor cardiac condition before starting a prosthetic rehabilitation program aimed at the restoration of the walking ability. A poor cardiac condition may increase both the risk of coronary accidents during the rehabilitation process as well as influence the progress of the rehabilitation. These aspects are in addition interrelated; a high coronary risk imposes or possibly should impose certain restrictions in the rehabilitation program in order to remain within safety limits. Also patients with a poor cardiac condition are possibly less inclined to exert themselves to the same degree as non cardiac subjects.

As preliminary results of a study (8) we observed relatively high cardiac loads during walking exercises by vascular amputees. This was not unexpected in view of the following considerations:

- Comparison of non-amputees walking at the same speed as trained amputees with leg prostheses showed an increased energy consumption ranging from 10 percent in unilateral below-knee amputees to 40-100 percent in unilateral above-knee amputees (7,9).

- An even higher energy consumption is expected when untrained amputees are learning to walk again, where the additional effort has to be accomplished by an uncoordinated gait pattern.
- In the period before and after their leg-amputation the subjects have led a sedentary life which has diminished their physical condition.

Since information concerning the vascular legamputees is scanty, we decided to evaluate the cardiac condition of this group and to relate it to the degree of prosthetic walking attained at the end of the rehabilitation process.

Graded exercise testing has been used with increasing frequency in the diagnosis of coronary artery disease. Furthermore exercise tests performed according to a suitable protocol provide valuable diagnostic information about the functional capacity of the cardiovascular system and form a rational basis for recommandations on physical activities in these patients (4,6).

During this study we subjected all vascular leg amputees admitted to our rehabilitation centre during a certain period to graded exercise testing in order to obtain an impression of their cardiac condition and physical work capacity.
For the sake of this study we defined cardiac condition as the peak heart rate (PHR) obtained during graded exercise testing without objective (as observed on the electrocardiogram (ECG)) or subjective (as stated by the patient) cardiac problems. The heart rate is considered to be a good index of the myocardial oxygen consumption, (10) and can therefore be used as an index for the cardiac load. Similarly the peak heart rate is an index for the peak cardiac load.
The measure used for maximum physical work capacity was the peak work load obtained during the test. Because there is no evidence of a linear relation between the work load and the heart rate in

elderly leg amputees performing rowing ergometry (see Methods), as there is in bicycle ergometry in healthy subjects, we used both measures for evaluation.

As we were primarily interested in the cardiac load rather than in the sheer physical work capacity we did not perform respiratory measurements. This meant that a considerable burden for these elderly patients was avoided.

The group of vascular leg amputees was examined without selection in order to obtain an impression of unknown aspects such as:

- the cardiac condition of amputees initiating a prosthetic rehabilitation program
- the exercise-induced cardiac problems as visualized on the electrocardiogram.
- the obtained peak heart rate provoked by exercise testing as a measure of the cardiac condition
- the applicability of graded exercise testing in these patients

The rehabilitation result, defined as the degree of prosthetic walking attained was established at the conclusion of the rehabilitation program. These results were compared with the findings of the exercise test performed at the initiation of the rehabilitation program. This comparison provides an impression whether there is a relation between a patient's exercise test performances at the beginning and the prosthetic walking result at the end of the rehabilitation program.

In another study we investigated the implications of a poor cardiac condition for the prosthetic rehabilitation progress and results. Therefore, besides the measurements presented in this paper, levels of cardiac load induced by performing various rehabilitation exercises are also recorded. The preliminary results will be presented by Cruts, (8).
Knowledge of a patient's cardiac condition and the cardiac loads as induced by specific exercises can be used by the physiotherapist to stay within safe levels of activity, while optimizing therapeutical intensity.

Methods

- Patients.

The Roessingh rehabilitation centre in Enschede in the Netherlands admits leg amputees for prosthetic rehabilitation after their discharge from hospital. Patients with a leg amputation because of peripheral vascular disease who started a prosthetic rehabilitation program at the Centre in the period January 1982 - May 1983 were included in this study. The population consisted of 28 men and 11 women with a mean age of 67.4 ranging 43 to 92 years.

The level of the unilateral leg amputations in men (women) were in 7 (6) cases above-knee amputations, in 9 (2) cases through-knee and in 8 (2) cases below-knee amputations. Of four male bilateral leg amputees two patients had both through-knee amputations, one patient had two below-knee and one patient had one above-knee and one below-knee amputation. One female patient had

two below-knee amputations.

All patients had a complete history and physical examination. A standard 12-lead electrocardiogram was obtained immediately before the exercise test. All patients had a history of peripheral vascular disease. Additional diagnosis included 18 cases of diabetis mellitus. Other non cardiac factors present that could adversely effect the prosthetic rehabilitation were: cerebral vascular accident (3 patients), blindness (2), deafness (1), arthritis (1), lung embolism (1) and Parkinson's disease (1).

- The exercise test.

The graded exercise test was performed on a specially designed ergometer (1), as shown in figure 1. It consists of a load unit on which the seated patient exercises by turning two cranks against a variable torque. Both cranks point in the same direction so the patient pushed or pulled with both arms simultaneously during exercise. The resulting rotation permitted coordinated trunk movement with the use of large body muscles. We called the apparatus provisionally a rowing ergometer.

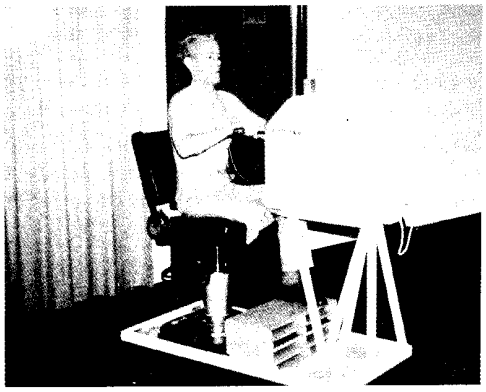

Figure 1.

The rowing ergometer in operation.

The patient took a seat on the ergometer chair which was positioned at wheelchair height. The patient was secured with a hip seat belt and swiveled into the exercise position. The height of the chair was adjusted and fixed so that the fulcrum of the cranks was at shoulder height and the load-unit position was adjusted to the length of the patient's arm. The patients were asked to maintain a speed of 50 revolution per minute although the load controlled by the load unit (make Lode) is in a wide range independent of the rotational speed. The speed was indicated by means of green and red lamps that were easily interpreted by patients who were visually handicapped.

The test work-load protocol was set at zero load to allow the rotating parts of the ergometer to attain working speed, followed by an initial load value of 30 Watt. This load was increased every minute by 10 Watt until the patient was unable to continue the exercise or the physician stopped the test.

As stated before we used the ECG to detect an upper limit in the attainable cardiac load. If an ischaemic response or rhythm disturbances occured, the heart rate involved was considered the maximum cardiac load. The detection of ST segment depression, abnormal beats and rhythms were required for this analysis of the ECG. If no ECG abnormalities were encountered, maximum cardiac load was identified as the heart rate obtained at maximum work load, were the patient was unable to continue the test.
The electrocardiogram was recorded using the bipolar leads CC5 and CM5 (3). The baseline drift and noise components over 100 Hz were removed by a hardware linear phase bandpass filter (1). The heart rate was recorded continuously by an Apple-II computer that also controlled the ergometer load protocol. The unfiltered and filtered ECG's were recorded on a Siemens Elema Oscillomink for 10 seconds every minute. Arterial blood pressure was measured before and within 15 seconds after conclusion of the exercise. The tests were performed under supervision of a cardiologist, who also performed the history examinations and judged the rest ECG and exercise ECG findings.

- Quantitative evaluation.

Besides the simple on-line processing and monitoring as described previously, the ECG's were analysed from an analog test recording. The processing by a computer system consisted of digital filtering, beat detection and morphological beat classification. Averaged beats were obtained from each morphological class and kept up-to-date (2). The heart rate versus exercise time were presented, as were the percentage of ECG beats incorporated in a specific morphological beat class. Morphological and time parameters were plotted after computer measurement from the most prominent beat class, containing the "normal" beats. Figure 2 shows a typical example of averaged beats and presents the morphological development of a beat class with the exercise time. The morphological parameters were measured on this type of averaged beat.

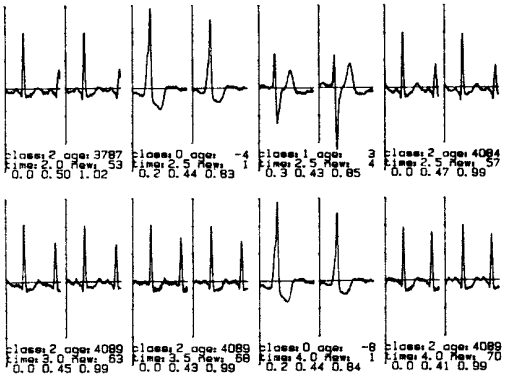

Figure 2. Typical example of averaged ECG beats presenting the morphological development of beat classes during exercise testing. The parameters plotted are: class number; age, a measure to remove unsuccessful classes; time, the time in minutes after the start of the test; new, the number of beats incorporated in the class

Results

- History and rest ECG findings.

Past myocardial infarction documented by history and characteristic evolutionary changes on the rest electrocardiogram were observed in nine patients. Further cardiac problems included four cases of left ventricle hypertrophy, three of bundle-branch block, three of essential hypertension, four of atrial fibrilation and one of mitralis insufficiency. These cardiac problems were diagnosed in 21 of the 39 subjects. Thirteen patients were on digoxine therapy and eight patients used beta-blocking agents. These therapies were continued during the test period.

- Graded exercise test findings.

Of the 39 patients, two were unable to perform the test, that is they were unable to continue the rowing exercise at the initial load value of 30 Watt for half a minute. One because of anaemia and the other because of polyneuropathy.
The peak performance in the exercise test in terms of peak work load and peak heart rate are shown in the histograms of figure 3. The mean peak work load was 63 Watt ± 3.4 SEM and the mean peak heart rate was 124 beats per minute ± 3.6 SEM. The shadowed part of figure 3 represents the patients showing cardiac problems known from their history and rest ECG.

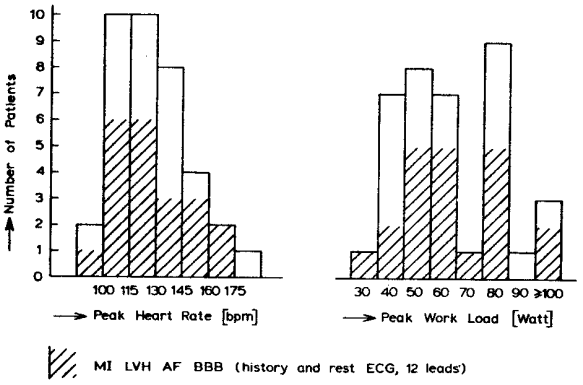

Figure 3.

Histograms of peak performance during graded exercise testing.

The mean of the increase in heart rate between rest and peak heart rate was 43 beats per minute ± 3.0 SEM. This figure did not change when the subjects using beta-blocking drugs were removed from the group.
The mean slope of the increase of heart rate versus the increase in work load during exercise was 0.72 ± 0.05 (SEM) beats per minute per Watt.

In fourteen patients ST-segment depressions of more than 1 mm horizontal or down sloping were seen in the ECG at peak work load leading to early termination of the test in one patient. Of these patients five also showed a similar ST-segment depression at rest, previous to the exercise test. Digoxine therapy was used by eight of the fourteen patients, which made it uncertain whether the ST-depression was of ischaemic origin. In figure 4 these findings are specified in relation to peak work load and peak heart rate.

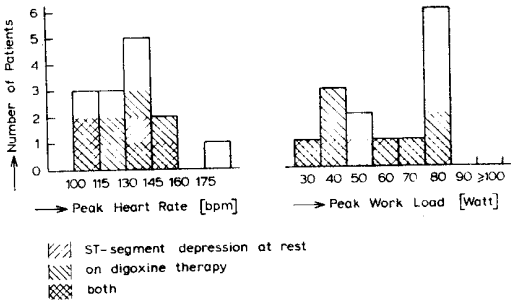

Figure 4.

Histogram of the number of patients with more than 1 mm ST-segment depression during maximum exercise, arranged in classes of peak heart-rate and peak work load.

During the exercise test on three patients aberrant beats were seen during exercise and exceeded with one patient for more than 10% of all beats in a 30 second period. Four patients had aberrant beats within five minutes of concluding the exercise with a peak percentage ranging from 8 to 12. One patient showed aberrant beats during exercise, with a peak of 16 percent, and during relaxation, with a peak of 13 percent, but also showed ventricular extra systole at rest. Presence of aberrant beats caused no early test terminations.

In those patients where the subjective stop criteria were noted, was this for 59 percent due to general fatigue, for 18 percent arm muscle fatigue and for 23 percent the unability to maintain the desired rotational speed. No patient terminated the test because of chest pain.
The individual test data in terms of peak heart rate versus peak work load are presented in figure 5. In this figure the patients

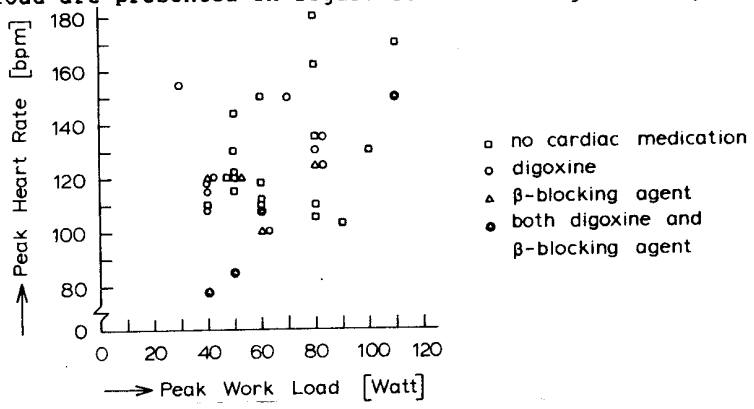

Figure 5. Individual exercise test data. Patients who were on digoxine therapy or used beta-blocking agents are marked as such.

who were on digoxine therapy or who used beta-blocking drugs are marked. In an attempt to compare the peak heart rate with normal subjects of the same age we were confronted by a lack of data of this age group. Therefore we decided to use the moderate extrapolated relations of AF Calvert (5) that were obtained in normal subjects aged 16-62 years. The relations are presented in the following expressions:

PHR (AGE) = 201 - 0.6 x AGE (± 11 SE) (male)
PHR (AGE) = 192 - 0.7 x AGE (± 12 SE) (female)

AGE is the age in years of the subject.
PHR (AGE) is the peak heart rate predicted for age in beats per minute in normal subjects performing graded bicycle exercises.

Related to this expression our patient group reached a mean value of 80 ± 2.3 (SEM) percent of the peak heart rate predicted for age, which is significantly different from 100 percent. A histogram of the distribution of these percentages is shown in figure 6.

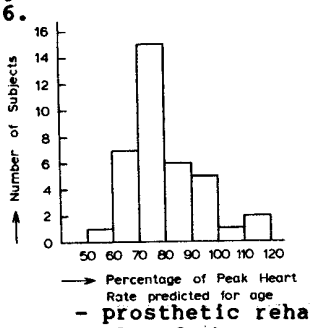

Figure 6.

A histogram of the percentage of peak heart rate in vascular leg amputees (achieved during rowing exercise) of the extrapolated nomogram of peak heart rate predicted for age (A.F. Calvert, 1977 for bicycle exercise).

- prosthetic rehabilitation result.

The result of the completed rehabilitation program is classfied according to the level of walking with a leg prothesis. We distinguished three levels.

Level 1: Conclusion of rehabilitation without a leg prothesis.
Level 2: Ability to walk with a leg prothesis with the help of a walking frame. The radius of action is less than 40 metres, and only suitable for walking indoors.
Level 3: Ability to walk with a leg prothesis for more than 40 metres, with or without the use of a walking stick or crutches. Able to walk outdoors.

Of the bilateral leg amputees three were classified at level 1, one at level 2 and one has not yet completed rehabilitation after 8 months of treatment.
The thirty-four unilateral leg amputees have all completed their prosthetic rehabilitation. Two of them were classified at level 1, one of whom suffered a cerebral vascular accident during the rehabilitation period, eleven at level 2 and the other twenty-one at level 3.

- Relation between rehabilitation result and exercise test.

In figure 7 the results of the completed rehabilitation programs of unilateral amputees were classified in the three level scale and arranged in histograms according to peak heart rate and peak work load. Figure 7b shows that subjects who achieved a peak work load of more than 60 Watt all attained the highest rehabilitation level.
The mean performances of unilateral amputees during the exercise test were significantly different for the ten subjects who achieved prosthetic walking level 2 from those twenty-one who achieved level 3. Their mean peak heart rates were respectively

113 ± 7 (SEM) and 130 ± 4 (SEM) beats per minute, and their mean peak work loads were respectively 44 ± 3 (SEM) and 71 ± 4 (SEM) Watt.

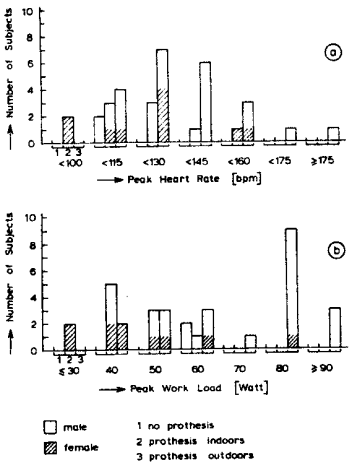

Figure 7.

Histograms of unilateral amputees achieving a specific level of prosthetic walking versus their performance during exercise testing at the start of rehabilitation.

Conclusion

Cardiac problems are common in elderly vascular amputees as shown in this study. Although these findings are not compared with a normal group of the same age, the information is of importance because the amputees are initiating a program of rehabilitation exercises known to provoke high heart rates.
More than half of the amputees had a known history of myocardial infarction, regular digoxine therapy or an abnormal rest ECG. Electrocardiography during exercise testing added previously unrecognized cardiac problems indicated by ST segment depression and the presence of aberrant beats. From these findings a cardiologist can determine a maximum safe heart rate for a specific patient while exercising, as an indication for the physiotherapist.
Differences in maximum heart rate and work capacity in previous studies relate to the individual population evaluated, the physical fitness of the group, the form of exercise stress applied and the exercise protocol utilised (5). A disadvantage of leaving out respiratory measurements was that the endpoint of the exercise test was determined by the patient which therefore included a certain subjective bias (13). Because of the subjectivity of the endpoint of the test in patients who reached their peak heart rate trouble-free, this may not be the maximum attainable.

The maximum work capacity as indicated by the peak work load during rowing exercise with a mean of 63 Watt seems low, indicating a poor physical condition. Here comparison with a normal group of a similar age is missing.

In spite of their poor cardiac and physical condition, of the thirty-four unilateral amputees, all but two where able to walk with a leg prothesis at the end of the rehabilitation program. A global comparison between the initial exercise test findings and the rehabilitation results shows that patients with a maximum work capacity of more than 60 Watt achieved the ability to walk outdoors with a prothesis.
Thirty-eight percent of the patients with a lower work capacity achieved the same rehabilitation level.

Rowing exercise with ECG recording is an applicable way of exercise testing in vascular leg amputees that provides measures for cardiac condition and physical work capacity. The findings can be used to advise safe heart-rate limits for rehabilitation exercises, preventing cardiac problems becoming dominant. It is not possible to predict the prosthetic rehabilitation result from the initial exercise test findings. A good performance indicated by a high peak work load and a high peak heart rate increases the change on a good prosthetic rehabilitation result.

REFERENCES

(1) J.A. van Alstê, W. van Eck, O.E. Herrmann.
Methods for exercise electrocardiography in patients unable to perform leg exercise: Rowing ergometry, Robust averaging and Linear phase filtering.
IEEE Computers in Cardiology, Florence 1981, pp. 465-468.

(2) J.A. van Alstê, E.D. Luursema, H.E.P. Cruts, O.E. Herrmann.
Beat-to-beat analysis of waveshape and rhythm in XECG using inner vector product hardware.
IEEE Computers in Cardiology, Seattle, 1982, pp. 355-358.

(3) C.A. Ascoop.
ST Forces during exercise.
Thesis 1974, R.U. Groningen. Schotanus & Jens, Utrecht.

(4) C.G. Blomqvist.
Use of exercise testing for diagnostic and functional evaluation of patients with atherosclerotic heart disease.
Circulation 44: 1120, 1971.

(5) A.F. Calvert, L.B. Bernstein, I.K. Bailey.
Physiological responses to maximal exercise in a normal Australian population - comparative values in patients with anatomically defined coronary artery disease.
Austr. N.Z. J. Med. (1977) 7, pp. 497-506.

(6) J.P. Clausen.
Circulatory adjustments to dynamic exercise and effect of physical training in normal subjects and patients with coronary artery disease.
In: Exercise and heart disease.
Sonnenblick, E.H., Lesch, M. (Eds.)
Grune & Stratton, 1977, pp. 39-75.

(7) P.J. Corcoran.
Energy expenditure during ambulation.
Phys. Basis Rehabil. Med. 1971 (10), pp. 185-198.
(8) H.E.P. Cruts, J.A. van Alstè, K. Huisman, J. de Vries.
Cardiac loads during prosthetic training in leg amputees.
The eight international symposium on external control of humanextremities.
Dubrovnik, Yugoslavia, 1984. (submitted).
(9) W.J. Erdman, Th. Hettinger, F. Saez.
Comparative work stress for above-knee amputees using artificial legs or crutches.
Occup. Ther. a Rehab. 1960, pp. 225-232.
(10) F.L. Gobel, K.A. Nordstrom, R.R. Nelson, C.R. Jorgensen, Y. Wang.
The rate-pressure product as an index of myocardial oxygen consumption during exercise on patients with angina pectoris.
Circulation, 57, 1978: 549-556.
(11) E.A. Hamilton, P.J.R. Nichols.
Rehabilitation of the Elderly Lower-Limb Amputee.
British Medical Journal, 1972, 2, 95-99.
(12) T. Kavanagh, R.J. Shephard
The application of exercise testing to the elderly amputee.
C.M.A. Journal, Febr. 1973, Vol. 108, pp. 314-317.
(13) N. Matsumura, H. Nishijima, S. Kojima, et al.
Determination of anaerobic threshold for assessment of functional state in patients with chronic heart disease.
Circulation, Vol. 68, 1983: 360-367.
(14) E. Peizer.
On the energy requirements for prothesis use by geriatric amputees.
Nat. Academy of Sciences - Nat. Research Council.
Conference on the geriatric amputee (Publ. 919), Washington 1961, pp. 146-150.
(15) M.G.N. Poulssen.
Bejaarden en beenamputaties in Limburg. (in dutch)
Ned. Tijdschrift v. Fysiotherapie. Vol. 92, nr. 2, pp. 32-35.