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Rewarming curves and derived parameters in the diagnosis of hand-arm vibration syndrome

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Hand-arm vibration syndrome; diagnosis; thermography; rewarming

Summary
Background: *Exposure to hand-arm vibrations is a known cause of the Hand-arm vibration syndrome (HAVS), a progressive syndrome beginning with sensory loss and leading to gangrene, making timely diagnosis essential.* **Objectives:** *Assessment of the usefulness of 9 diagnostic parameters claimed as being of greatest value in the diagnosis of HAVS, and examination of the complementary diagnostic value of the curve shapes.* **Methods:** *Three groups of subjects (HAVS cases, exposed workers without irreversible changes, and controls) were examined by cold provocation followed by thermographic imaging, obtainment of rewarming curves for four preselected regions and calculation of parameters. The discriminative value of individual parameters and the discriminative power of a combination of all the parameters were assessed. Qualitative curve shape analysis was included.* **Results:** *The greatest individual discriminative ability is associated with RT (rewarming time to pre-cooling value, $p<0.001$), Tmax (maximum temperature during the 10-minute recovery, $p<0.001$), k (rewarming rate, $p<0.012$) and RD (rewarming delay, $p<0.031$). The discriminant analysis yielded one significant discriminant function (Wilks' $\Lambda = 0.278$, $\chi^2(18)=48.67$, $p<0.001$, canonical $R^2=0.63$). Four types of rewarming curves were identified.* **Conclusions:** *RT, Tmax, k and RD appear to be the most suitable individual parameters for group discrimination. When linearly combined, the parameters can be useful for discriminating HAVS cases from both Controls and Claimants, which constitutes the main task of an occupational health physician. Additional information is available from the qualitative assessment of the rewarming curve shape.*

Riassunto
«Curve di riscaldamento e parametri derivati nella diagnosi della sindrome da vibrazioni mano-braccio». **Introduzione:** *L'esposizione a vibrazioni mano-braccio è una causa riconosciuta della sindrome da vibrazioni mano-braccio (HAVS), una sindrome progressiva che va dalla perdita sensoriale fino alla cancrena, rendendo essenziale la diagnosi precoce.* **Obiettivi:** *Lo scopo del presente studio è la valutazione dell'utilità di 9 parametri diagnostici proposti come di rilevante importanza nella diagnosi di HAVS, nonché l'esame del valore diagnostico complementare delle forme delle curve di riscaldamento.* **Metodi:** *Sono stati indagati 3 gruppi di soggetti (casi di HAVS, la-*

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voratori esposti ma senza alterazioni irreversibili, e controlli) mediante test di stimolazione al freddo e termografia per immagini, ottenendo curve di riscaldamento per 4 regioni predeterminate. Sono stati valutati il valore discriminante dei singoli parametri e di una combinazione di tutti i parametri. È stata inoltre effettuata l'analisi della forma delle curve. **Risultati:** *La maggiore capacità discriminante è risultata associata al tempo o di riscaldamento fino al valore precedente al raffreddamento (RT, p<0,001), alla temperatura massima durante il recupero di 10 minuti (Tmax, p<0,001), alla velocità di riscaldamento (k, p<0,012), e al ritardo del riscaldamento (RD, p<0,031). La combinazione di questi parametri ha prodotto una funzione discriminante significativa (Wilks' Λ=0,278, χ^2(18)=48,67, p<0,001, R^2=0,63 canonico). Sono stati identificati 4 tipi di curve di riscaldamento.* **Conclusioni:** *Tra i parametri indagati RT, Tmax, k e RD sembrano essere i più idonei per discriminare tra diversi gruppi. Combinandoli linearmente questi parametri possono essere utili per discriminare i casi di HAVS sia dai controlli che dai lavoratori senza alterazioni irreversibili.*

List of abbreviations

HAVS	(Hand –Arm Vibration Syndrome)
VWF	(Vibration-induced White Finger)
RP	(Raynaud's phenomenon)
FST	(Finger skin temperature)
CPT	(Cold Provocation Test)
RT	(rewarming time to pre-cooling value)
RT21	(rewarming time to 21°C)
k	(rewarming rate)
Q	(area under the rewarming curve)
Qc	(area above the rewarming curve)
RD	(rewarming delay)
LTD	(longitudinal temperature difference)
P5	(percentage of the pre-cooling temperature after 5 minutes)
Tmax	(maximum temperature during the 10 minutes recovery)

Introduction

Occupational exposure to vibrations is recognized as a cause of the hand-arm vibration syndrome (HAVS) (2). The syndrome is characterized by neurological symptoms, principally tingling and numbness, and by vascular symptoms and signs typical of vasospasm (17). The neurovascular component of this syndrome is the Vibration-induced White Finger (VWF), a type of secondary Raynaud's phenomenon (RP), which manifests as episodic blanching of the fingers in response to cold. The blanching is due to a cessation of blood flow in the affected finger resulting from exaggerated cold-induced vasoconstriction (12). This vasospasm may be caused by hyperactivity of the sympathetic nervous system as well as by local changes in the fingers such as hypertrophy of arterial walls (7, 16).

Cold provocation tests involving measurement of finger skin temperature (FST) are often used to detect the abnormal cold response due to circulatory impairment in vibration-induced white finger (VWF) (1, 7, 9). Such tests typically involve cooling of a patient's hand in cold water, at a predefined temperature, for a predefined duration. Various methods of measurement of finger skin temperature have been proposed, ranging from thermocouples to thermography. Among the results of such measurements are rewarming curves, which are plots of temperature changes of the different regions of a patient's finger, during the hand rewarming phase, after cold immersion.

This study examines the parameters for quantitative characterization of the rewarming phase that were claimed to have the best ability to discriminate between healthy subjects and those suffering from changes due to HAVS. These parameters include the RT (rewarming time to pre-cooling value) (2), RT21 (rewarming time to 21°C) (21), k (rewarming rate) (10), Q (area under the rewarming curve) (13, 14), Qc (area above the rewarming curve) (13), RD (rewarming delay) (5), LTD (longitudinal temperature difference) (18), P5 (percentage of the pre-cooling temperature after 5 minutes) (13) and Tmax (maximum temperature during the 10-minute recovery) (13).

The goals of the present study were: (i) to determine the discriminative power of these parameters individually, and combined together, differentiating between the three groups: HAVS, Claimants and Controls, and (ii) to examine a complementary diagnostic value of curve shape analysis.

Methods

Subjects and medical examination

The sample consisted of 45 subjects. According to their working history and results of other diagnostic procedures (finger skin temperature, nail fold capillaroscopy, photoelectric plethysmography, neural conduction examination and bone X-ray), they were divided into three groups. The HAVS group (n=9) included male patients who had a history of at least five years of occupational exposure to hand-arm vibrations and changes consistent with HAVS. According to the Stockholm Workshop Scale (6, 16), they exhibited HAVS symptoms of at least 3 V and 2 SN. The Claimants group (n=20), 19 men and one woman, included patients who had a history of a minimum of five years of occupational exposure to hand-arm vibrations, but did not develop changes consistent with HAVS. Lastly, the Controls (n=16), 15 men and one woman, were people who worked in similar conditions to those in the other two groups (e.g. a worker was from the same company as one of the members of the other two groups) but neither performed any tasks with hand-arm vibration-producing tools nor had any previous occupational exposure to hand-arm vibrations or symptoms of Raynaud's phenomenon of any other origin.

The subjects from HAVS and Claimants groups were patients who claimed for HAVS as an occupational disease. All of the subjects in the HAVS and Claimants groups were chainsaw operators except for three subjects in the Claimants group who were chipper and grinder workers in a foundry using pneumatic chipping hammers and hand-held rotary vibrating tools. Although the subjects from the HAVS and Claimants groups had long-term exposure to high levels of hand-arm vibration, only the 9 subjects from the HAVS group had advanced HAVS status consistent with requirements for recognition of HAVS as an occupational disease. Such requirements are: substantial pathological changes in the vascular system and in at least one of the other two systems affected by vibrations, including musculoskeletal and nervous. HAVS status was recognized on the basis of objective changes verified by several standard diagnostic methods: FST, nail fold capillaroscopy, photoelectric plethysmography, neural conduction examination and bone X-ray. Changes consistent with HAVS included, for example: a reduced number of capillary vessels and at least two fingers with numerous microcapillary bleedings (capillaroscopy); reduced nerve conduction velocities on *n. ulnaris* and *n. medianus*, increased terminal latencies (EMNG); small, characteristic bone cysts and vacuoles in the hand and wrist bones (X-ray). The subjects who were exposed to hand-arm vibrations but did not meet the criteria for an occupational disease (using the same diagnostic methods) were placed in a group termed "Claimants".

All subjects underwent a thorough medical examination including immunological, biochemical and haematological tests to exclude any other known causes of secondary RP. The subjects taking any medication known to affect the vascular system were excluded from the study. The subjects were asked to refrain from smoking for 1 day before the test. Ambient temperature was maintained constant, and all subjects were allowed to acclimatize for 30 minutes. All subjects gave their informed consent to participate. The characteristics of the groups are shown in table 1.

Cold test and thermography

The examination protocol was based on thermographic recording with an IR camera (Wöhler type IK-21). Following acclimatization (room temperature 22±1°C), the subject assumes the position for the recording, putting his hand in the adjustable support. The background temperature is determined using a standard procedure with crushed aluminum foil (8). The determination of the skin emissivity is then performed, by adjusting the infrared camera temperature reading to the reading of a contact thermometer on the same spot on the

Table 1 - Characteristics of subjects

Group	n	Age (years)		Exposure duration (years)		Current smokers
		Mean	SD	Mean	SD	
HAVS	9	52.0	3.5	24.4	4.7	3
Claimants	20	49.4	5.7	20.1	5.5	8
Controls	16	46.9	9.2	-	-	14

skin. The support is then adjusted, and a single pre-cooling thermogram is recorded. The subject then puts a closely fitting latex glove on the hand under examination, and this hand is immersed up to the wrist in stirred water at a temperature of 8°C for the duration of 5 minutes. During cooling, care is taken to prevent the palm and fingers from firmly pressing against the bottom of the cooling vessel.

After cooling, the subject removes the hand from the cold water, and the latex glove is quickly removed by the operator, who also uses paper tissue to very quickly wipe the talcum powder residue away from the palm, as it may affect its radiative properties. The subject assumes the same position as in recording the pre-cooling thermogram. A recording procedure follows, lasting 30 minutes, with a thermogram recorded every 30 seconds. This produces a sequence of 61 consecutive thermograms that are later used to reconstruct the 30-minute rewarming curve for every point on the palm of the hand, or a rewarming curve for pre-defined regions, using the mean temperature of all points within that region. This is achieved by a specially developed MathCAD® 13 application. Using the rewarming data, rewarming curves for the index and middle finger were generated, and then used to derive the aforementioned parameters for each subject.

Example rewarming curves are shown in figure 1. These were obtained for four pre-defined regions: Region 21 (distal phalanx of the index finger), Region 23 (proximal phalanx of the index finger), Region 31 (distal phalanx of the middle finger) and Region 33 (proximal phalanx of the middle finger). The meaning of the parameters under assessment is as follows (figure 1). RT (rewarming time to pre-cooling value) (2) is the time taken for the temperature to reach the pre-cooling level, which is given by a pre-cooling thermogram. RT21 (rewarming time to 21°C) (21) is the time taken for the temperature to reach 21°C during rewarming. k (rewarming rate) (10) is the parameter obtained from the assumed exponential rewarming $T(t)=T_0+\Delta T(1-e^{-kt})$, obtained by fitting the exponential function to the recorded data, where k describes the speed of the exponential rewarming process. Q (area under the rewarming curve) (13, 14) is not simply the opposite of Qc (area above the rewarming curve) (13) in that Qc is calculated relative to the pre-cooling temperature, so Qc includes this information, whereas Q does not. The rewarming delay (RD) (5) can be observed in figure 1 (b): in some cases, there is a very slow, almost linear initial rewarming, followed by a sudden exponential "relaxation," i.e. sudden increase in the blood flow. The RD is the time taken from the beginning of rewarming to the onset of rapid rewarming, if present. If it is not present, it is taken to be zero; if, on the other hand, rewarming is very slow (nearly linear) during the whole process, it is taken to be 30 minutes (equal to the total recording time) as shown in figure 1 (c). The LTD (longitudinal temperature difference) parameter is calculated as the temperature difference between the finger tips and finger bases before cooling. When taken as a pre-cooling value, it was found to be "a major thermographic parameter to discriminate between patients with and without definite Raynaud's phenomenon" (18) so it is included here as such. The remaining two parameters are, P5 (percentage of the pre-cooling temperature after 5 minutes of rewarming) (13) and Tmax (maximum temperature reached during the 10 minutes from the beginning of rewarming) (13). All the parameters were calculated for distal

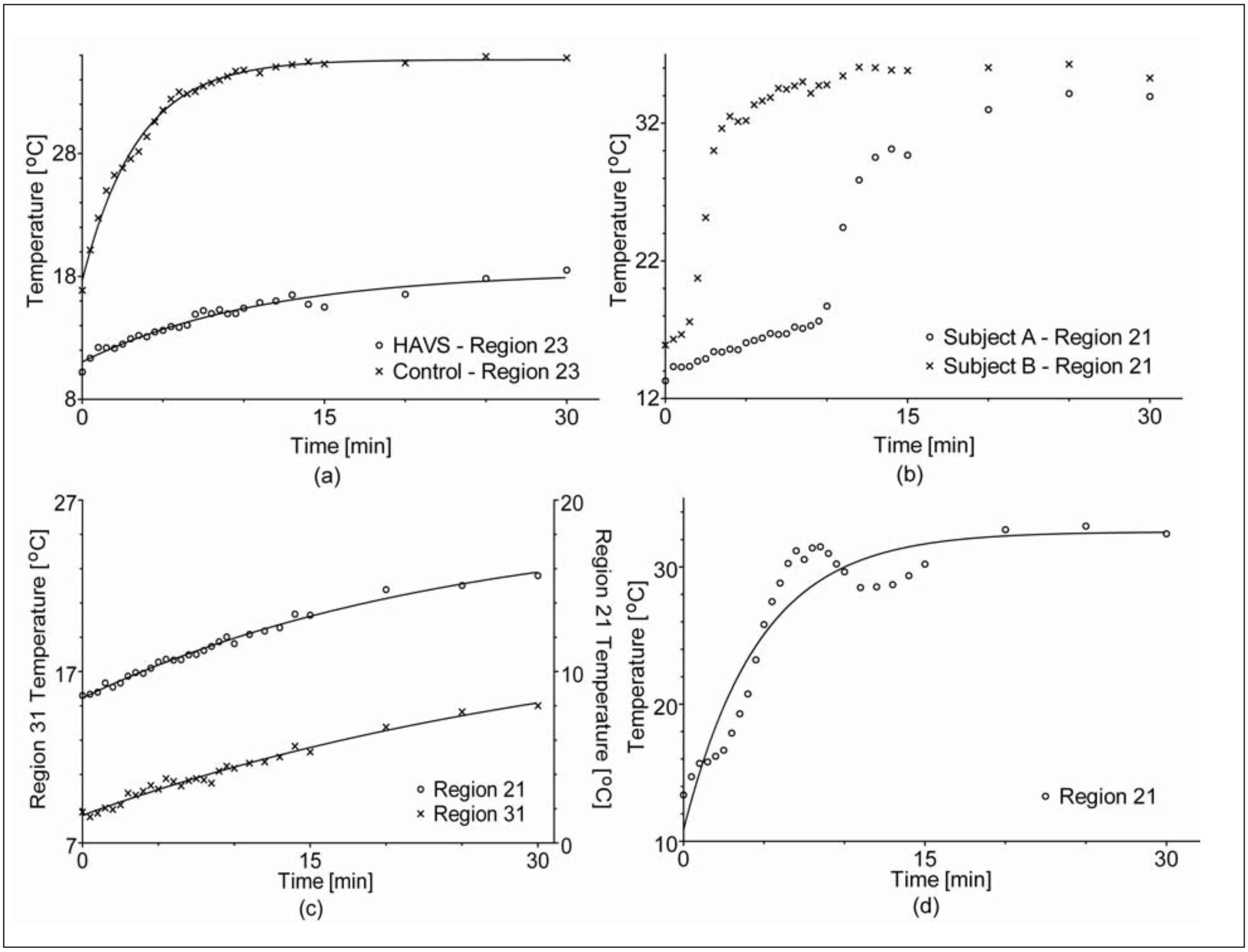

Figure 1 - Example rewarming curves: (a) an example of HAVS and Control subject; (b) subjects "A" and "B" are both from the Claimants group; (c) both curves belong to the same HAVS subject (the two curves are for two different regions); (d) a subject from the Claimants group

phalanges, except the LTD which, by definition, includes information about the proximal region temperature.

The aforementioned parameters, used for quantitative characterization of the rewarming phase, were used as predictor variables in our analysis. The dependent variable was group membership (HAVS, Claimants, and Controls).

The parameters that were obtained for Region 21 were correlated to a high degree with the corresponding parameters for Region 31 (almost all of the correlations were above 0.80). Therefore, we decided to use only the set of parameters obtained for Region 21 in further analyses.

Statistical methods

The analysis of relationships between parameters was performed using the Bravais-Pearson correlation coefficient. The discriminative value of individual parameters in distinguishing the three groups was assessed by separate one-way analyses of variance with each individual parameter as a dependent variable. For determining the discriminative power of all the parameters taken together in distinguishing the three groups, a canonical discriminant analysis was used, in which these 9 parameters were used as predictor variables. The analysis was done using PASW® 17 software.

Results

The arithmetic means and standard deviations of the three groups, for the parameters that were used as predictor variables in the discriminant analysis, are shown in table 2.

The results of the analysis of discriminative power of individual parameters, obtained by separate one-way analyses of variance (with individual parameters as dependent variables, and the group as a factor) are shown in table 3.

It follows from table 3 that the highest discriminative ability in differentiating between groups is associated with RT, Tmax, k and RD when parameters are assessed individually. Other parameters, taken alone, show no significant discriminative power as there are no statistically significant differences between the means of the groups for those parameters. The results of post-hoc multiple comparisons (Bonferroni's test) revealed significant differences between the HAVS and both the Claimants and the Controls groups with respect to RT and Tmax parameters, while for k and RD parameters such difference was found only between the HAVS and Controls groups.

Since there are significant and relatively high correlations between the parameters themselves (table 4), the combined discriminative power of all 9 parameters was examined using discriminant analysis. This analysis yielded one significant discriminant function (Wilks' Λ=0.278, $\chi^2(18)$=48.67, p<0.001, canonical R^2=0.63). The magnitude of the squared canonical correlation for a significant discriminant function implies a moderate discriminative power of a combination of all the parameters used in distinguishing between the three groups.

Table 3 - Results of analyses of differences between groups (F statistics, p values and η^2) by individual parameters

Parameter	F*	P	η^2
RT [min]	8.73	.001	.29
k [min^{-1}]	4.90	.012	.19
Q [min×°K]	1.97	.152	.09
RD [min]	3.77	.031	.15
LTD [°K]	.40	.674	.02
RT21 [min]	2.28	.114	.10
Qc [min×°K]	.44	.650	.02
P5 [%]	2.54	.091	.11
Tmax [°C]	8.16	.001	.28

*df1=2, df2=42

Standardized coefficients for a statistically significant discriminant function and the function-parameters correlations (i.e. coefficients of the structure of this function) are shown in table 5.

The group centroids on the first discriminant function are given in table 6, and the classification results based on the combination of all the parameters are given in table 7. The results in table 5 suggest that the greatest specific contribution to the discriminant function is due to the variables RT, RT21 and Tmax. The examination of the group centroids (table 6) reveals that the centroid of the HAVS group on the discriminant function is far from the centroids of the two remaining groups, while the centroids of the Claimants and Controls

Table 2 - Parameter means (M) and standard deviations (SD) of the three groups

Variables	HAVS (n=9)		Claimants (n=20)		Controls (n=16)	
	M	SD	M	SD	M	SD
RT [min]	18.76	10.34	10.39	8.96	5.47	2.11
k [min^{-1}]	.10	.10	.27	.22	.35	.19
Q [min×°K]	776.98	77.35	865.07	179.94	900.52	137.42
RD [min]	9.50	12.40	3.95	9.23	.09	.38
LTD [°K]	-1.15	1.31	-1.56	1.69	-1.23	.86
RT21 [min]	4.20	4.31	6.43	9.27	1.72	1.44
Qc [min×°K]	35.76	74.19	-2.04	119.33	-2.97	113.51
P5 [%]	74.65	18.67	85.48	29.77	96.56	16.63
Tmax [°C]	24.28	4.51	29.53	7.01	33.08	1.89

Table 4 - Intercorrelations of parameters

	1	2	3	4	5	6	7	8	9
1. RT [min]	-	-.49**	-.71**	.74**	-.21	.63**	.65**	-.66**	-.78**
2. k [min^{-1}]		-	.60**	-.43**	.13	-.37*	-.36*	.60**	.64**
3. Q [min×°K]			-	-.54**	.31*	-.72**	-.68**	.64**	.76**
4. RD [min]				-	-.14	.54**	.45**	-.55**	-.66**
5. LTD [°K]					-	-.42**	.09	-.03	.32*
6. RT21 [min]						-	.54**	-.68**	-.79**
7. Qc [min×°K]							-	-.74**	-.48**
8. P5 [%]								-	.76**
9. Tmax [°C]									-

*p≤.05, **p≤.01

Table 5 - Standardized canonical discriminant function coefficients and discriminant function-parameter correlations for the first discriminant function

Parameter	Standardized canonical discriminant function coefficients	Discriminant function-parameter correlations
RT [min]	**.788**	0.453
k [min^{-1}]	.009	-0.346
Q [min×°K]	-.066	-0.224
RD [min]	-.118	0.290
LTD [°K]	.253	0.053
RT21 [min]	**-1.703**	0.016
Qc [min×°K]	-.153	0.109
P5 [%]	.226	-0.221
Tmax [°C]	**-1.741**	-0.429

Table 6 - Group centroids on the first discriminant function

Group	Centroids
HAVS	2.54
Claimants	-0.52
Controls	-0.75

are close to each other. Hence, the combination of parameters differentiates well between the HAVS and the two remaining groups, but it does so much less successfully between the Claimants and Controls.

A similar conclusion can be drawn by inspecting table 7: out of 9 HAVS cases, only one was misclassified as Claimants; but 4 out of 20 subjects from the Claimants group were misclassified as Controls, while 6 out of 16 Controls were misclassified as Claimants.

Table 7 - Classification results based on the combination of all parameters when data for the subjects to be classified are used in constructing the classification function

Group	n	Predicted group membership		
		HAVS	Claimants	Controls
HAVS	9	8 (88.9%)	1 (11.1%)	0 (0.0%)
Claimants	20	2 (10.0%)	14 (70.0%)	4 (20.0%)
Controls	16	0 (0.0%)	6 (37.5%)	10 (62.5%)

Table 8 - Classification results based on the combination of all parameters using the "holdout" method

Group	n	Predicted group membership		
		HAVS	Claimants	Controls
HAVS	9	6 (66.7%)	3 (33.3%)	0 (0.0%)
Claimants	20	2 (10.0%)	11 (55.0%)	7 (35.0%)
Controls	16	0 (0.0%)	7 (43.8%)	9 (56.3%)

A more realistic estimate of classification success, based on the combination of parameters used, is obtained using the "holdout" method, which classifies the subjects consecutively, but where the data pertaining to the subject to be classified are not used in constructing classification function. The results of this type of classification are shown in table 8. According to these results, somewhat less than half of the subjects from the Claimants and Controls groups were misclassified, while a third (3 out of 9) of the HAVS cases were misclassified. It is important to note that none of the controls were misclassified as HAVS cases, and that none of HAVS cases were misclassified as controls.

An interesting result of the discriminant analysis is that suggesting a specific contribution of the RT21 parameter to the discriminant function. Although RT21 alone has no significant discriminative power (table 3 shows that the groups are not significantly differentiated by the means on the RT21 variable), the standardized coefficient of this parameter in the discriminant function is very high (table 5). It would appear that this parameter, when used in combination with other parameters, plays the role of a suppressor: from the remaining predictors, it eliminates the variance that is not important for group discrimination. On the other hand, Qc and LTD exhibit no discriminative power, neither alone nor in combination with other parameters. In a repeated discriminant analysis, in which these two parameters were removed from the set of predictors, the same value was obtained for the squared canonical correlation for the first discriminant function, and also the same classification success as in the discriminant analysis already presented.

In order to judge the diagnostic value of the discriminant function in HAVS, in terms of sensitivity and specificity, the results of the discriminant analysis from table 7 are presented in a different way in table 9. The subjects in table 9 are classified in the HAVS and NO-HAVS groups on the basis of advanced HAVS status taken as a gold standard, and according to the classification results of the discriminant function in which 9 diagnostic parameters, derived from the hand rewarming curves, were used as predictor variables. Hence, all subjects not diagnosed with HAVS (Claimants and Controls groups) were classified as NO-HAVS.

Table 9 - Sensitivity and specificity of the discriminant function in diagnosis of HAVS

	Correct diagnosis		
Discriminant function	HAVS (+)	NO-HAVS (-)	Total
HAVS (+)	8	2	10
NO-HAVS (-)	1	34	35
Total	9	36	45

According to the data in table 9, the sensitivity of the discriminant function as a diagnostic test was 88.8%, specificity was 94.4%, the positive predictive value was 80% and the negative predictive value was 97.1%.

Discussion

The available literature suggests that rewarming curve shapes, in addition to parameters derived from them, could also be of diagnostic value. According to Lawson (11), curve shape proved valuable in identifying primary Raynaud's cases, dysthermia and normal subjects. Dupuis (4) reported characteristic rewarming patterns in patients with vibration white finger (VWF). Temperature recovery in healthy persons exhibited exponential behaviour. Incomplete rewarming after 30 minutes following cold provocation was indicative of impaired vascular reactivity due to VWF and reported to be of diagnostic value on an individual basis (20). According to Darton and Black (3), thermographic images of the hands and rewarming curves after cold provocation show characteristic differences among patients with primary and secondary Raynaud's phenomenon, and normal subjects.

We were able to distinguish among four typical curve shapes for regions 21, 23, 31 and 33. The first represents expected standard exponential rewarming (figure 1(a)). Most of the curves fall into this category, but the exponential process can be faster or slower, so an example of both is shown. The second type represents delayed rewarming characterized by very slow, almost linear initial rewarming, followed by a rapid exponential "relaxation," i.e. sudden increase of the blood flow (figure 1(b) – Subject A). This is a very common phenomenon, encountered in other published papers (5, 11, 19, 21). This rewarming delay was quantified by Gautherie (5), and if it exceeded 4 minutes, this was considered to be one of the criteria for what he defined as "Dysthermia". The occurrence of delay can easily be detected by curve shape analysis.

The third curve type looks almost linear or like a very slow exponential (figure 1(c)) and is indicative of severely obstructed blood flow, causing very slow rewarming. Curve shape analysis immediately reveals low rewarming rates, which constitutes another criterion for dysthermia (rewarming rates under 3°C/min) (5). Obviously, this would constitute a pathological finding, such as the one described by Lawson and Nevell (11) as a "typical tracing of primary Raynaud's disease". The differentiation between primary Raynaud's disease and HAVS may be possible by considering the degree of asymmetry of the responses to cold between individual fingers (5).

The fourth type is distinguishable by large oscillations in temperature during the rewarming process. Figure 1(d) is an extreme case of this. While most curves are exponential with minimal superposed oscillations, the other three types are not uncommon. It would probably be most accurate to say that each recorded rewarming curve is a superposition of more than one of the identified types, with a dominant tendency (exponential, oscillatory, linear...). Some cases show a good exponential, but also a minute or two of rewarming delay (Figure 1(b) – Subject B). This would not meet a criterion for a dysthermia (5), and would yield a valid k value.

The example curves from figure 1 provide an opportunity to understand why the curve shape, not just the derived parameters, can be of diagnostic value. The delayed rewarming pattern, as shown in figure 1 (b), can be immediately identified. The Q area under the curve can be the same for different curve types (pure exponential, oscillatory and the one exhibiting delayed rewarming), yet the underlying haemodynamics can be very different. Exponential curve fitting required for calculating τ (15) or k (10) may not completely succeed in cases lacking good exponential conformity. The P5 parameter can vary immensely if delayed rewarming occurs, and its onset is just before or just after the 5 minute threshold. The maximum finger temperature during 10 minutes of rewarming depends on the individual subject's characteristics, not only on the presence of HAVS. Similar observations can be made about most of the derived parameters in common use.

Conclusions

The parameters for quantitative characterization of the rewarming phase that were assessed in this study, when appropriately linearly combined, can be useful for discriminating HAVS cases from both Controls and Claimants, which constitutes the main task of an occupational health physician. However, these parameters do not appear to contain enough information to discriminate between the Claimants and the Controls groups. When assessed as single quantifiers, the greatest discriminative ability is associated with RT, Tmax, k and RD.

Regarding the lack of success in discrimination between the Claimants and the Controls groups, the following should be considered. The Claimants were exposed to low levels of hand-arm vibrations, usually not associated with significant damage. In addition, not everybody with occupational exposure to hand-arm vibrations develops HAVS due to various reasons including individual susceptibility. Finally, the neurovascular changes underlying HAVS may be reversible depending on the stage of disease.

It should be borne in mind that the results of this study were obtained from a relatively small number of subjects. Hence, further investigation is recommended to validate the findings.

The rewarming curves provide information from their shape as well as from their quantitative determinants. Interpreting the curve features, in addition to some quantifiers derived from it, offers additional insight into the process in individual cases, so the goal of assessing subjects on an individual basis can be more readily attained. Hence it may be advisable to include the rewarming curves in individual case reports and documentation of the results of thermometric examinations based on cold provocation.

No potential conflict of interest relevant to this article was reported

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