Application of VPI as a Diagnostic Aid to ECG Abnormalities in Flying Personnel

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Abstract

VENTILATORY Pulse Index (VPI) values were experimentally determined for 7 IHD cases and 11 cases of ECG abnormalities under different grades of exercise. These were compared with VPI data collected on athletes and non-athletes. The VPI work load curves do not show any peak value in the case of diseased subjects unlike the other groups. This is explained as a failure of cardio-respiratory coordination process.

Introduction

The greatest use of electrocardiogram as a diagnostic aid is perhaps in detecting the ischaemic changes, due to inadequacy of coronary flow, scarring of myocardium and of the conducting tissues. The incidence of false positive or false negative results is not clearly established, due in part to lack of precise anatomic, electrocardiographic and physiologic correlations and in part to lack of standardisation of exercise tolerance tests themselves.

The purpose of the exercise test is primarily to unmask any latent inadequacy of coronary flow, by increasing the heart rate, muscular work and oxygen consumption to a point that the resultant ischaemic of myocardium if any, is reflected on the electrocardiogram. But non specific ECG changes in healthy individuals under exercise test raise a serious doubt as to whether the noted changes are due mainly to metabolic factors like pH variations or fluctuations in serum K^+ level or due to ischaemia or due to other reasons.

On one hand healed infarcts though may show permanent ECG changes in an individual, may not suffer from myocardial functional deficiency; on the other, a resting ECG may be entirely within normal limits in a patient who has clear cut and indisputable angina pectoris, or coarctation of aorta, small ventricular septal defects, and small patent ductus. "Therefore in absence of clinical and other corroborative evidences, the so called significant ECG changes are at the most testimonial in nature but never a conclusive evidence of myocardial ischaemia and far less, a commentary on the functional status of the myocardium"[3]

In an earlier study[6] we have reported that physical fitness can be measured with good accuracy by using a new index which we termed as Ventilatory Pulse Index (V.P.I.). This index is based on the hypothesis that cardio-respiratory system is one functional unit so far as oxygenation of the tissues is concerned. V.P.I. is calculated from the formula:

$$\text{V.P.I.} = \frac{O_2 \text{ consumption in ml (S.T.P.D.) Sqm/hr} \times 100}{\text{Heart rate/min} \times \text{Ventilation in litres (ATPS)/hr}}$$

With increasing grades of exercise at submaximal level, the cardiorespiratory system reaches a level of optimal efficiency at a certain work load depending upon its functional status. If there is any functional impairment in the system, it shows an "optimisation"

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point (peak) at lower grades of work load. Conversely, failure to attain "optimisation" point (peak) would indicate a breakdown in the coordination process either due to functional impairment of one or both the subsystems[6].

Based on the above hypothesis a study was undertaken in order to measure the VPI of athletes, non athlete healthy individuals, IHD cases and persons showing non specific ECG changes.

Method and Materials

47 subjects in the age group 21 to 52 years were given bicycle ergometer exercise at increasing grades in the range of 30 to 110 watts at the submaximal level. Table I gives the details of the subjects who participated in the present study.

Eighteen of these subjects had ECG abnormalities of various descriptions but mainly ST-T changes either at rest or after exercise or both. Seven subjects (out of 18) were diagnosed as recovered Ischaemic Heart Disease (IHD) cases. They were under periodic reviews. Rest of the 11 subjects were otherwise healthy individuals, completely asymptomatic but showed ECG changes mainly in ST-T, after treadmill exercise.

Non-athlete subjects were drawn from a group who were due for commissioning in the service and belonged to a lower age group (21 - 33 years). 19 service athletes (Army) constituted the athletes group. They were subdivided into sub-group I and II. Athletes I were short distance runners whereas athletes II were long distance runners.

Each subject was given bicycle ergometer exercise for 5 minutes at each work load with a rest interval of 30 minutes between the exercises. This schedule was followed to ensure safety, and, to maintain uniformity in approach in all the groups. IHD cases particularly, could not continue with exercise for more than 5 minutes at a stretch at higher work loads.

Expired air was collected in a Douglas bag during last 1½ minute of exercise. Expired air samples were analysed in a microscholander gas analyser for oxygen consumption and carbon dioxide output. Minute ventilation was measured with the help of Meterfav-... volume meter.

Heart rate was recorded during the last 30 second of each exercise, on a multichannel Grass Polygraph.

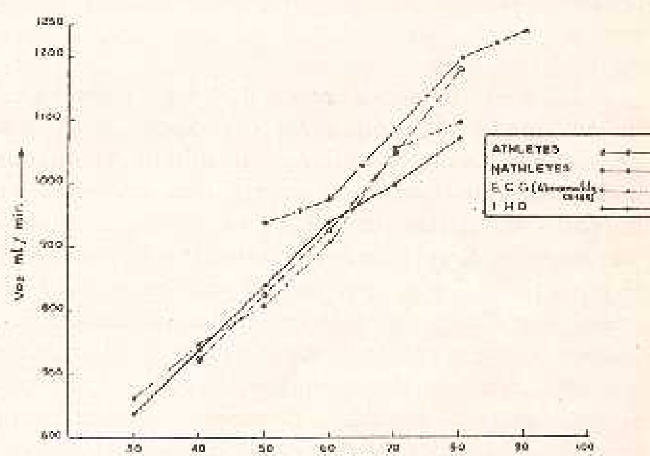
Surface area was computed from the height and weight records of the subjects using Du Bois nomogram.

Results

Oxygen consumption: Mean values of oxygen consumption (VO_2lit/hr STPD) for different grades of exercise at the submaximal level is given in Table II and is graphically represented as ml/mt STPD in fig. 1. Two characteristic features may be noted from the graph. First, except for the non-athletes, the other groups did not show a linearity in the slope in oxygen consumption with the intermittent type of exercise, unlike what is normally observed in a continuous type.

MEAN OXYGEN CONSUMPTION (VO_2 ml/min/STPD) OF VARIOUS GROUPS OF SUBJECTS AT DIFFERENT WORK LOADS

FIG. 1



Oxygen consumption per heart beat (VO_2 ml/beat) is given in Table III. Which shows that non athletes consumed less oxygen than IHD and ECG abnormality groups in the range of 40 to 70 watts. At 80 watt level non athletes showed better oxygen consumption than the IHD but less than ECG abnormality group.

Ventilation: With increasing grades of exercise ventilation showed a progressive rise. Table IV gives the values. In 60 to 80 watt range, the non-athletes ventilated less compared to ECG abnormality and IHD groups. Athletes group II ventilated the least compared to other groups in the 70 to 80 watts range.

Heart Rate: Showed a progressive rise with increasing grades of exercise in all the groups except the IHD and the results are given in Table V. In the IHD group, the rise in the range of 50 to 70 watts was insignificant.

Discussion

During submaximal exercise the distribution of blood flow which is an important determinant of physical efficiency, is closely related to the capacity of the cardio-vascular system[5]. Therefore, any cardiac pathology which restricts the functional capacity of the heart as a pump, is logically expected to reflect its effect on the oxygenation of the tissues. The latter in turn will have its link with the respiratory system and therefore compensatory mechanism like increased minute ventilation, increased extraction of oxygen from the blood, greater a–v oxygen difference etc are expected to be brought into play in view of cardiac efficiency. The degree of comsumption will be directly proportional to the functional capacity of both the cardio-vascular as well as the respiratory system.

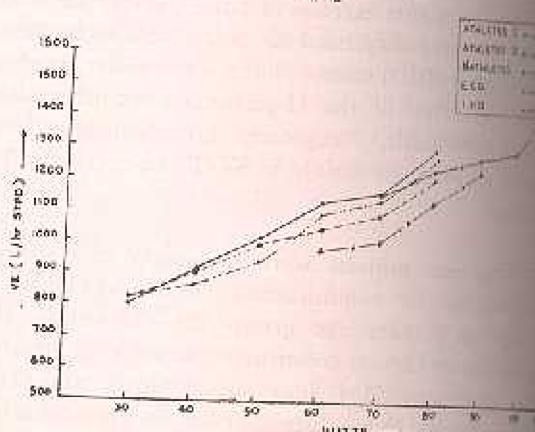
Keeping the above points in view, three interlinked important components of compensatory mechanisms ie, oxygen consumption, minute ventilation and heart rate have been taken into consideration in the formulation of VPI. A similar approach was made by Kirchoff and Lauschner[4] in formulating oxygen pulse (OP). But in our earlier studies[6] we found that OP suffered from certain inconsistencies. In day to day events intermittent type of exercise is more common than continuous type of exercise as in athletic events. Therefore assessment of functional capacity of the cardio-respiratory system should be based on more realistic model than the determination of VO_2 max. as is the common practice today. The latter is more appropriate for athletes but not for the sedentary individuals, the aged and the infirm.

The importance of cardio-respiratory adjustments in physical exercise was observed by Ekholm et al[2], after 16 weeks of physical training on a bicycle ergometer at submaximal level. The subjects showed an increase in O_2 uptake by 20% and lowering of heart rate by 16%. According to these authors, increase in O_2 uptake was partly due to more extraction (increased a-v oxygen difference) and partly due to an increase in stroke output. The other possibilities not mentioned by the authors are increase in ventilation perfusion ratio and increase in the availability of O_2 in the pulmonary alveoli. Whatever be the reason in the present study the athletes showed the best oxygen consumption capacity followed by non athletes, ECG abnormality and IHD groups in that order.

The first evidence as to the important role of respiratory system in the oxygenation of tissues during exercise comes from the degree of minute ventilation in different groups with increasing grades of exercise (fig. 2). Herein it is observed that in the range of 60–80 watts, the athletes ventilated the least followed by non-athletes; ECG abnormality and IHD groups. At lower grades of exercise the latter three groups did not show significant difference between themselves. But above 60 watts the differences are more discernible.

MEAN VENTILATION VALUES (VE/ATPS) OF VARIOUS GROUPS AT DIFFERENT WORK LOADS

FIG. 2

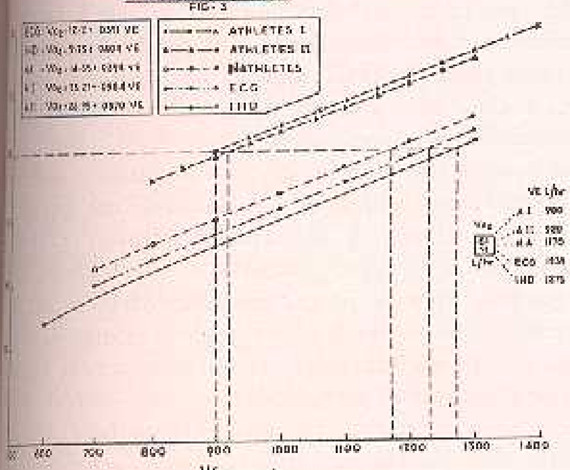


The relationship between VO_2 and VE (fig. 3) highlights the importance of ventilation further. The graph drawn on the basis of regression equations for different groups, clearly indicate that athletes (AI and A II) extracted far more oxygen than the other groups for the same degree of ventilation, followed by non athletes, ECG abnormality and IHD groups.

Debate concerning the magnitude and significance of blood flow redistribution has been long and active. Experimental work in this field was thoroughly reviewed by Wade and Bishop[9]. They concluded that marked redistribution of blood flow does occur during exercise in both normal and diseased subjects. To that extent the cardio-vascular system, the reflexes and the metabolites play a big role in determining the

...ance to exercise and therefore indirectly the oxygen consumption. According to Rowell[5], in normal subjects, pulmonary factors impose no limitation on oxygen transport. Were it so then there should be no difference in VE for the corresponding VO_2 in different groups. But the present study clearly revealed that there were marked differences in ventilation in different groups for the corresponding VO_2 which indicated that there were different degrees of respiratory adjustments according to cardiac efficiency of the groups (fig. 3).

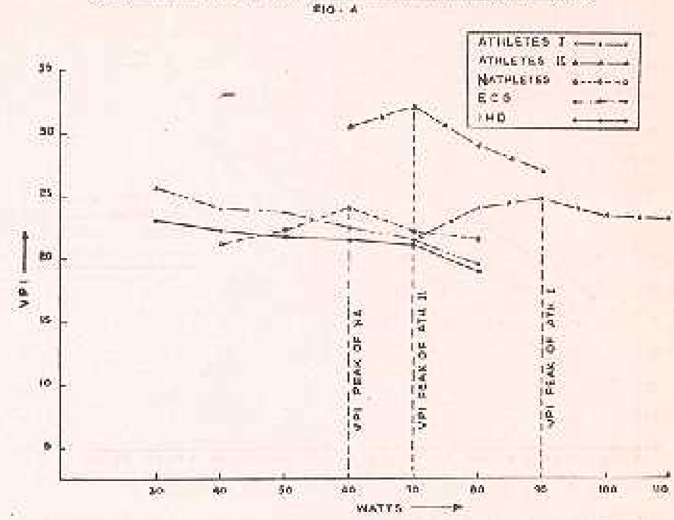
VENTILATORY EFFICIENCY (VO_2/VE) OF VARIOUS GROUPS AT INCREASING WORK LOADS
FIG-3



In normal subjects stroke volume and heart rate are in reciprocal relationship particularly in athletes[7]. Therefore it is expected that if for some reason the heart rate is not increased as in the case of old age people, the only alternatives will be to increase the stroke volume and oxygen extraction rate in order to increase VO_2. To that it may be added, that when the stroke volume is itself restricted due to the diseased myocardium or insufficient coronary supply, the only alternative compensatory mechanism will be the respiratory system. The same point is well brought out in VE/VO_2 relationship, (fig. 3).

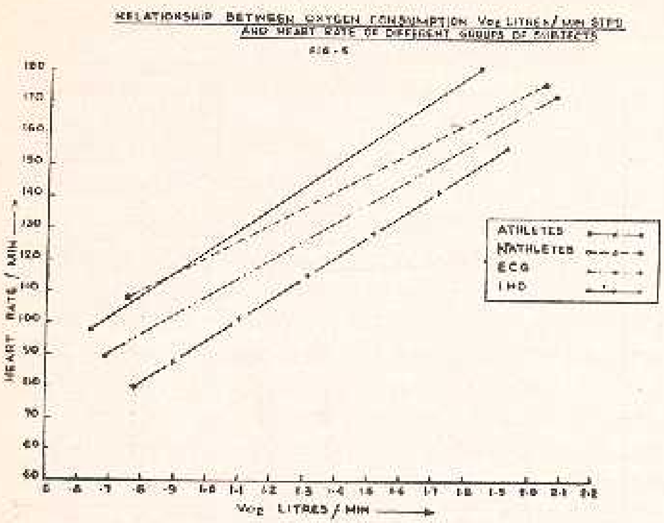
In the study of VPI scores on 33 subjects (fig. 4) it had been shown earlier[6] that the VPI in contrast to other physical fitness indices like oxygen pulse (OP) and physical fitness index (PFI) of Harvard Step Tests showed consistent pattern in the athletes I and II groups and non-athletes. In the latter group, the peak level of VPI was observed in the 50-60 watts range of exercise, whereas the athletes I and II showed the peak level at 90 and 70 watt levels of exercise

MEAN VPI VALUES OF VARIOUS GROUPS AT INCREASING WORK LOADS
FIG-4



respectively. It is noted (Table VI) that at 70 and 90 watt levels of exercise, there is parctically no difference in the heart rate between the two groups of athletes though VE differed considerably. At 70 watts level even the VO_2 was also almost identical in the two groups though VE differed considerably. In other words HR and VO_2 remaining identical if the VE varies under identical situation (at 70 watts) one is compelled to infer that the possible contributory role of ventilation in ensuring oxygenation of the tissues can not be over ruled as done by Rowell[5].

It may be observed (fig. 4) that unlike the athletes and the non-athletes, the IHD and ECG abnormality groups did not show any 'peak' in VPI. The moot question is, why the latter two groups failed to attain any peak VPI with increasing grades of exercise ? Could it be due to lack of 'optimisation' of cardio-respiratory adjustment as a result of cardiac pathology or could it be due to the failure of respiratory compersatory mechanism to meet the demand of oxygen by the tissues or both ? It appears that the IHD group showed signs of far more cardiac strain as reflected in the HR for a given rate of exercise compared to other groups (fig. 5). For instance, at a fixed level of 0_2 consumption of say 1.3 liter/min the HR for IHD group was 144/min compared to 115/min in the athletes and 136/min in non-athletes. But nonspecific ECG abnormality group had a HR of 127/min ie, less than the non athletes which is quite puzzling particularly so, in view of their failure to achieve the peak VPI. The plausible explanation for such a phenomenon could be that ECG abnormal group (non-specific) perhaps suffers from the same



handicap as the older age group, in that they fail to raise the HR and hence the cardiac output, though their 0_2 consumption (lower value after 70 watts) commensurated well with the lower heart rate. It is interesting to note in this connection that both IHD and ECG abnormal groups belonged to overweight class with large surface area (Table I). The discrepancy in oxygen consumption per heart beat as observed between non-athletes and ECG abnormal group (Table VI) tends to support this possibility. A definite answer to this question can however be settled only by direct estimation of stroke output. It is perhaps due to this limitation ie, failure to raise HR, the optimisation process of cardio-respiratory system was not observed in the ECG abnormality group and therefore no 'peak' VPI was observed. Indirectly it is perhaps an indication of premature onset of senile changes of reversible nature, because reversal of ECG to normal pattern after a diet schedule and exercise is not an uncommon finding in this group. Few cases of IHD with low VPI peak (at 40%) and a few cases of non specific ECG changes with normal VPI peak have also been observed. These cases are still under review and hence their results have not been included in the present report. It is suggested, that a finding of normal VPI peak during graded exercise is an indication of well compensated functional cardio-respiratory system. Abnormal ECG findings with low or no 'peak' VPI is a sure indication of cardio-respiratory functional deficiency. As a corollary, progressive shift of VPI 'peak' from low range to normal range will be an indication of recovery of cardio-respiratory system to normalcy irrespective of permanent ECG changes.

Conclusion

Usefulness of VPI as an aid to diagnosis of the functional state of cardio-respiratory system is due to the fact that it indicates the phenomenon of 'peak' and the point of work load at which it appears. Failure in the attainment of VPI peak as found in the present study in IHD and ECG abnormality cases was a clear indication of failure of cardio-respiratory co-ordination process at optimum level. Differences observed in the VPI peaks in the athletes and non athletes, were indicative of the different grades of functional efficiency of cardio-respiratory efficiency among these groups. Based on these results it is suggested, that a progressive improvement of VPI 'peak' from low to high or normal range of work load will be an indication of full recovery of cardio-respiratory system irrespective of non specific ECG changes or otherwise. Overweight may be a causative factor in dislocating the 'optimal' co-ordination between cardio-vascular and respiratory sub-system and thus affect VPI peak.

Acknowledgement

We are extremely grateful to Air Vice Marshal DN GUPTA, AVSM, PHS (DMS (Air)) for evincing keen interest in the present study and its follow up and to Air Commodore SP Verma, VM, Air Officer Commanding, IAM for his sustained support to the project.

We gratefully acknowledge Shri PLN Rao (Statistician of IAM) active help in analysing the results. Our heart felt thanks to all those subjects who ungrudgingly submitted themselves to the gruelling tests.

TABLE I

Details of the Subjects

Subjects		No	Age	Height Cms	Weight Kgs	Surface area
NON-ATHLETES	...	10	25.7 (21–33)	170 (163–184)	56.2 (49–64)	1.64 (1.5–1.83)
ATHLETES I	...	12	27.1 (20–44)	168 (160–183)	60.7 (50–79.5)	1.69 (1.5–1.95)
ATHLETES II	...	7	25.6 (22–31)	167 (165–170.5)	51.5 (50–64)	1.63 (1.53–1.71)
IHD	...	7	40.7 (26–52)	168 (155–179)	64.4 (57–83)	1.70 (1.57–1.95)
NON-SPECIFIC ECG ABNORMALITIES	...	11	31.4 (22–39)	170 (165–182)	65.1 (55–74)	1.75 (1.58–1.93)

TABLE II

Oxygen Consumption (VO_2 L/Hr STPD of Various Groups at Increasing Work Loads

	30W	40W	50W	60W	70W	80W	90W	100W	110W	120W	
ATHLETES I	—	—	—	—	64.1	69.8	75.2	84.4	91.2	—	Mean
	—	—	—	—	21.3	12.1	8.6	10.2	13.7	—	S.d.
ATHLETES II	—	—	—	59.6	64.9	73.3	78.0	—	—	—	Mean
	—	—	—	3.97	4.02	3.49	2.14	—	—	—	S.d.
NON-ATHLETES	—	42.93	50.2	55.38	61.83	68.48	—	—	—	—	Mean
	—	4.26	3.68	6.94	4.95	6.66	—	—	—	—	S.d.
ECG ABNORMALITY	39.8	44.5	48.9	55.1	63.3	66.1	—	—	—	—	Mean
	4.02	3.41	3.12	3.7	4.34	4.62	—	—	—	—	S.d.
IHD	38.4	44.5	61.3	56.4	60.9	67.9	—	—	—	—	Mean
	4.0	3.7	3.2	2.8	5.9	4.5	—	—	—	—	S.d.

TABLE III

Relationship between Increasing Work and Oxygen Consumption VO_2/MI (STPD)/Heart Bea

	30W	40W	50W	60W	70W	80W	90W	100W	110W
NON-ATHLETES	—	6.7	7.5	8.0	8.5	9.0	—	—	—
ATHLETES I	—	—	—	8.5	11.0	10.5	11.0	11.7	11.[illegible]
ATHLETES II	—	—	—	10.5	11.2	11.8	11.5	—	—
I H D	6.7	7.2	7.8	8.5	9.1	8.7	—	—	—
ECG ABNORMALITY	7.8	7.8	8.2	8.8	9.5	9.5	—	—	—

TABLE IV

Mean Ventilation (Ventilation L/HR STPD) of Various Groups at different Work Loads

	30W	40W	50W	60W	70W	80W	90W	100W	110W	120W	
ATHLETES I	—	—	—	—	1178	1237	1294	1413	1570	—	Mean
	—	—	—	—	97	117	138	138	122	—	S.d.
ATHLETES II	—	—	—	994	1014	1164	1259	—	—	—	Mean
	—	—	—	58.7	92.4	124	89.7	—	—	—	S.d.
NON-ATHLETES	—	910	1008	992	1095	1313	—	—	—	—	Mean
	—	164	142	155	161	177	—	—	—	—	S.d.
ECG ABNORMALITY	840	883	962	1101	1174	1298	—	—	—	—	Mean
	130.6	95.7	175.5	147	67.4	68	—	—	—	—	S.d.
IHD	821.5	902.4	1010.3	1139.6	1168.3	1326	—	—	—	—	Mean
	18.2	112	144	83.2	171	83.4	—	—	—	—	S.d.

TABLE V

Mean and Standard Deviation of Heart Rate/Min of Various Groups at Increasing Work Loads

	30W	40W	50W	60W	70W	80W	90W	100W	110W	120W	
ATHLETES I	—	—	—	—	100	111.5	114.3	122.3	157.0	—	Mean
	—	—	—	—	—	13.5	12.5	10.8	11.4	—	S.d.
ATHLETES II	—	—	—	95.1	97.0	104.4	112.8	—	—	—	Mean
	—	—	—	7.4	9.2	8:0	7.0	—	—	—	S.d.
NON-ATHLETES	—	108.9	112.2	116.2	122.6	129.6	—	—	—	—	Mean
	—	10.5	10.1	10.7	12.7	14.2	—	—	—	—	S.d.
ECG ABNORMALITY	84.4	95.5	100.4	104.5	112.0	116.4	—	—	—	—	Mean
	6.7	8.2	10.3	10.8	15.6	14.6	—	—	—	—	S.d.
IHD	98.0	105.0	110	113	122	132	—	—	—	—	Mean
	20.0	21.0	20.0	20.0	11.0	11.3	—	—	—	—	S.d.

TABLE VI

Comparision of mean VPI, OP, PFI, Mean Heart Rate, Mean Oxygen Consumption and Ventilation at 70W and 90W work loads

	ATHLETE I						ATHLETE II					
Work Load Watts	Mean HR/min	Mean VO_2/Lit/hr	Mean VE/Lit/hr	VPI Value	OP Value	PFI Value	Mean HR/min	Mean VO_2/Lit/hr	Mean VE/Lit/hr	VPI Value	OP Value	PFI Value
70	99	65.0	1455	21.5	10.9	159	99	64.9	904	31.7	10.9	159
				±4.7	±1.2	±15				±4.2	±0.7	±38
90	114	75.2	1646	24.6	11.1	148	113	78.0	1600	26.8	11.5	161
				±5.1	±1.2	±18				±3.3	±0.6	±32

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