Understanding the effect of nonstationarities over linear and non linear indexes derived from heart period variability series

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Introduction

Linear and non linear indexes derived from beat-to-beat variability series of heart period have provided important information about cardiovascular control mechanisms

The majority of these indexes assumes stationarity as a requirement

Usually stationarity is not rigorously tested and short variability series (about 300 samples) of heart period are supposed to be stationary as a result of carefully controlled experimental settings

Consequences of the presence of non stationarities over traditional linear and non linear indexes are little studied

Aims

1) to propose a simple test to check a restricted form of weak stationarity (i.e. the stability of mean and variance) on short heart period variability series.

2) to check the effects of non stationarities over linear and non linear indexes derived from heart period variability

Informal definition of stationarity

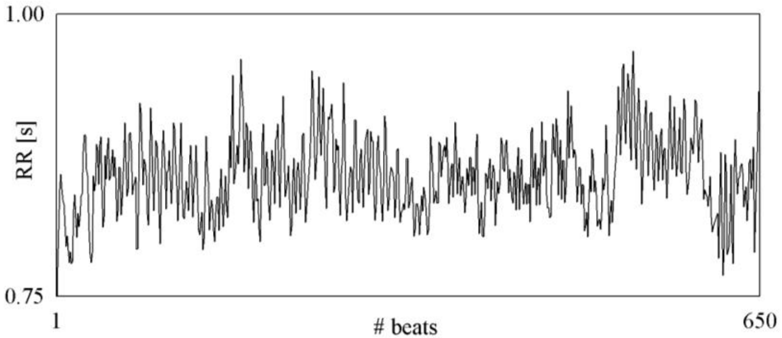
A temporal series is stationary if its statistical quantities of any order remain stable over the entire recording

A temporal series is weakly stationary if its statistical quantities of first and second order remain stable over the entire recording

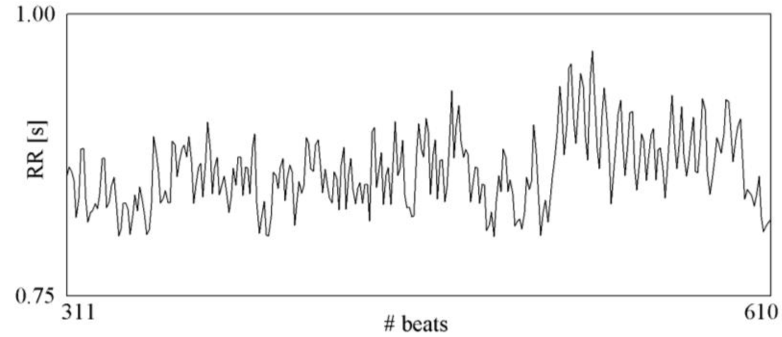
The restricted weak stationarity (RWS) test checks a limited form of weak stationarity

Restricted weak stationarity (RWS) test

$x=\{x(j), j=1, \ldots, J\}$



$x=\{x(i), i=j, \ldots, j+N-1\}$



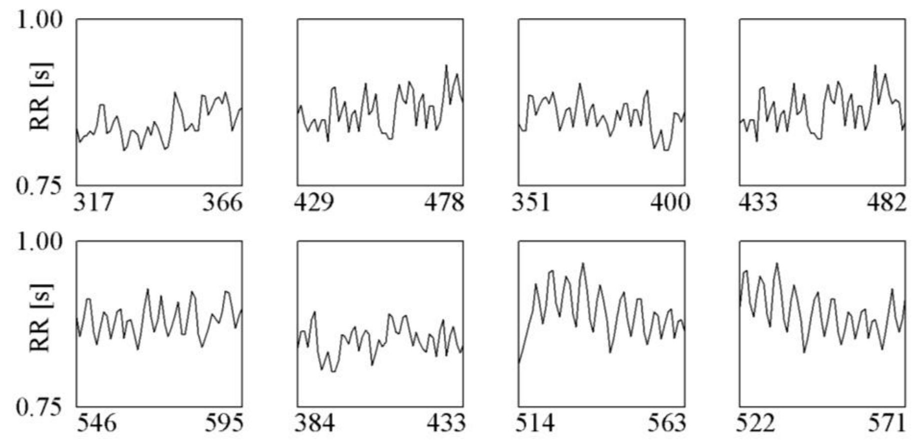
Kolmogorov-Smirnov test

yes → parametric analysis

no → non parametric analysis

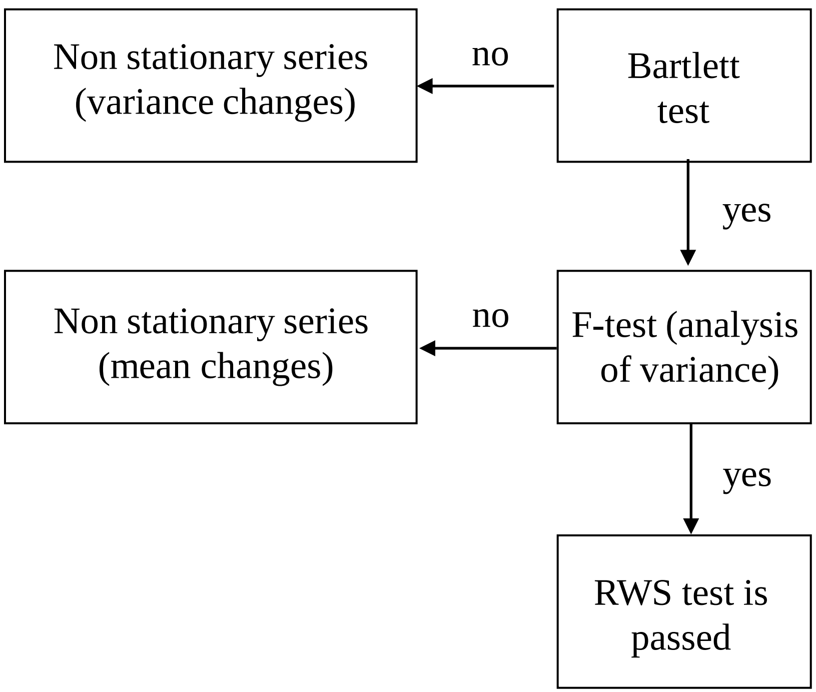
random selection of M patterns

$x_{m,L}(i)=(x(i), x(i+1), \ldots, x(i+L-1))$

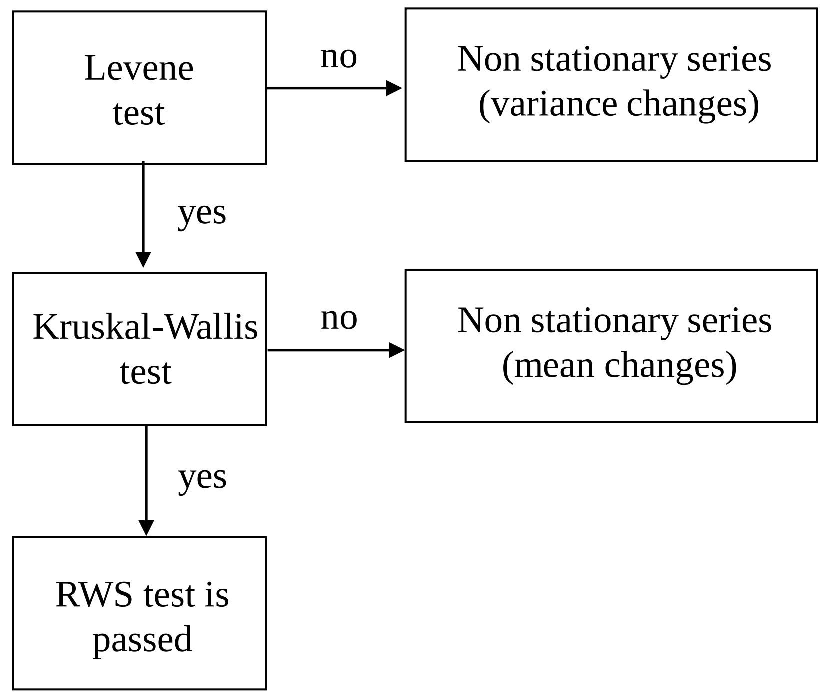


Restricted weak stationarity (RWS) test

Parametric analysis over M randomly selected patterns



Non parametric analysis over M randomly selected patterns



Restricted weak stationarity (RWS) test: parameter setting

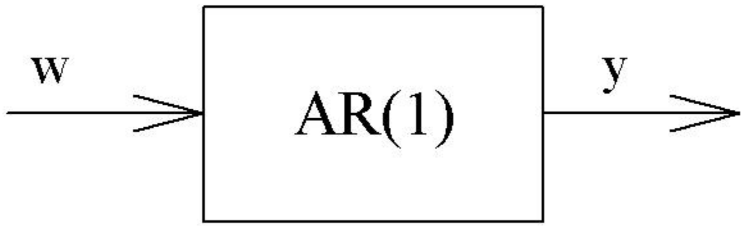
Series length N=300

Pattern length L=50

Pattern number M=8

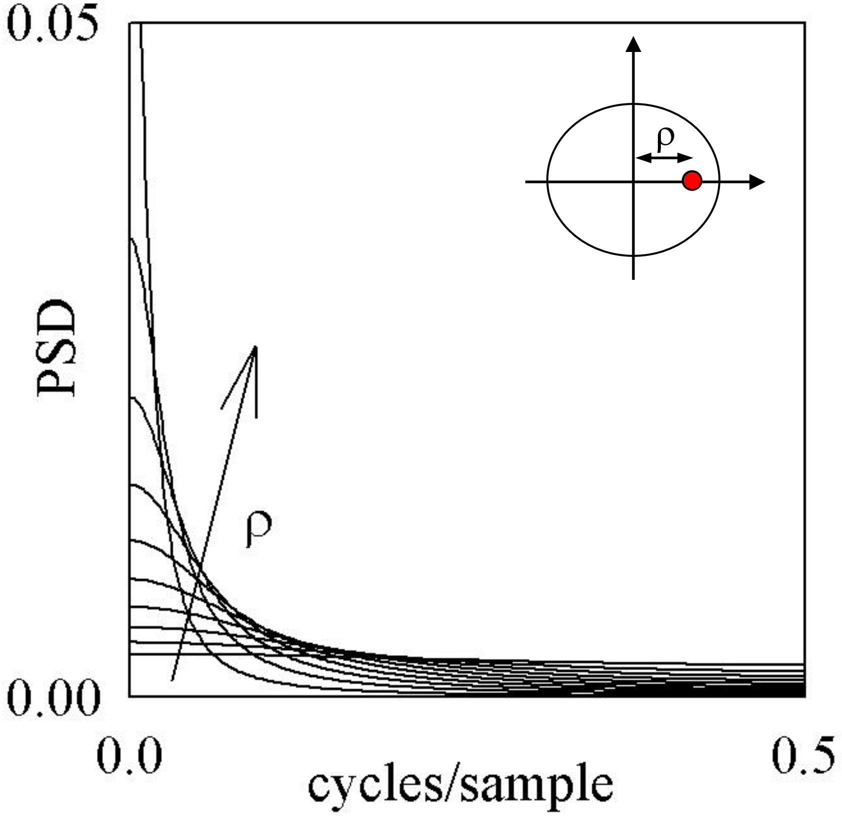
Level of confidence p=0.05

Type-1 simulation



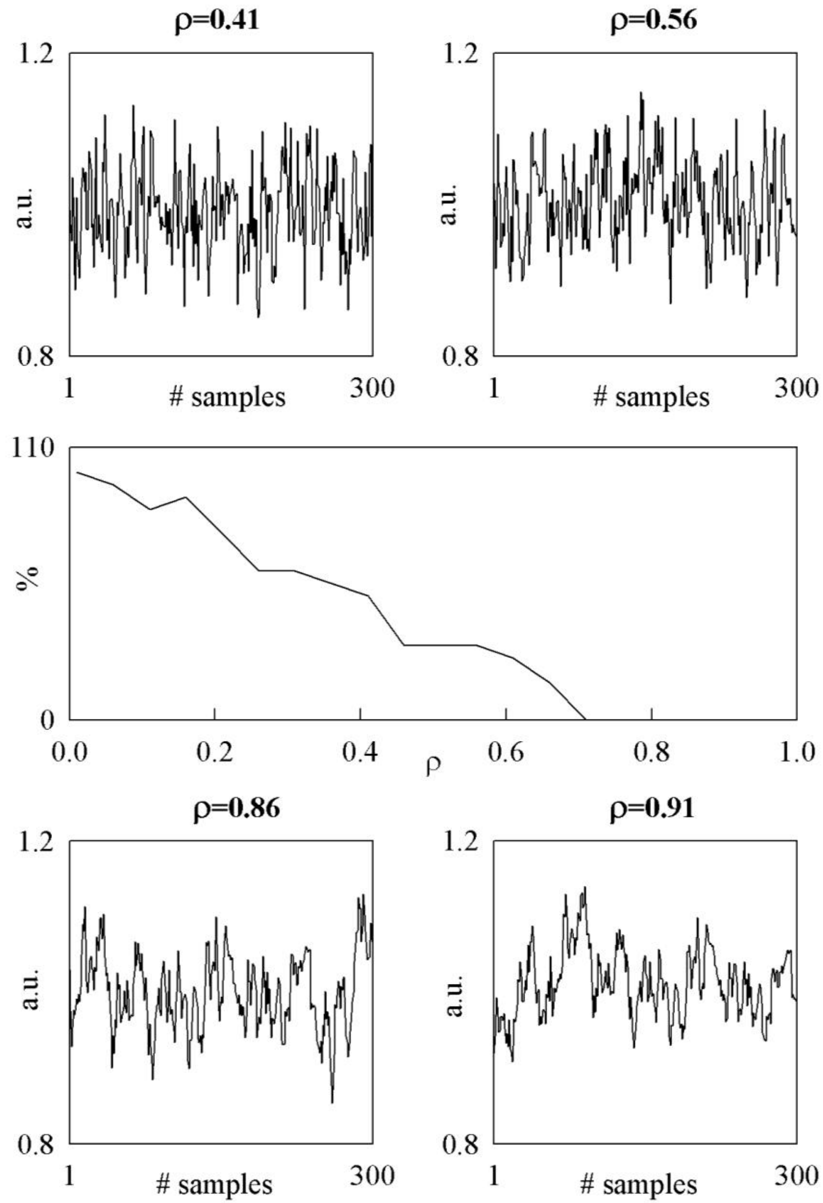
$z=\rho e^{j\phi}$

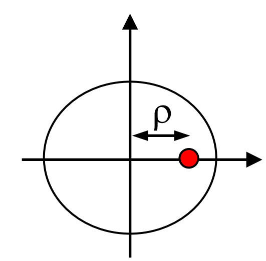
with $\phi=0$ and $0.01<=\rho<=0.91$



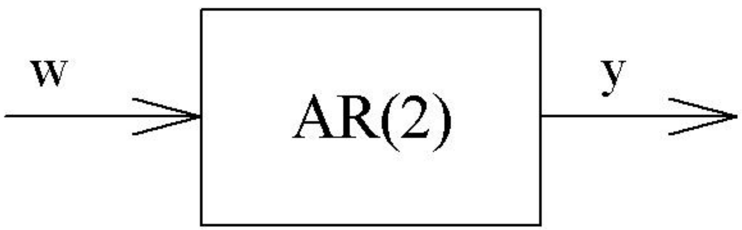
AR(1) realizations of 2000 samples: 20 sequences of 300 samples drawn at random from each AR(1) realization

Results over type-1 simulation: percentage of stationary segments



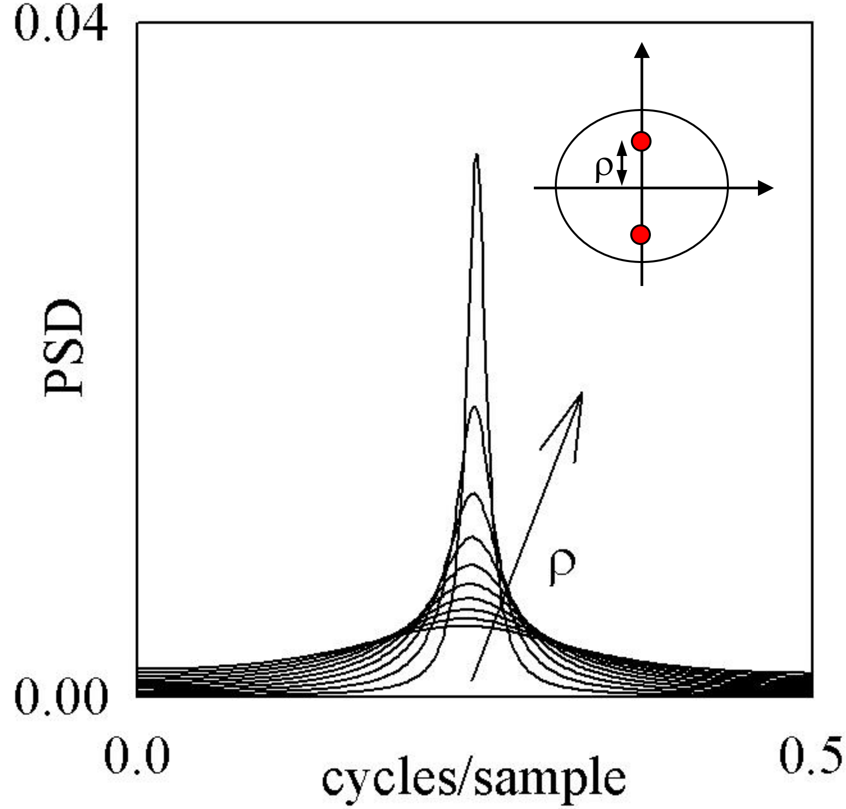


Type-2 simulation



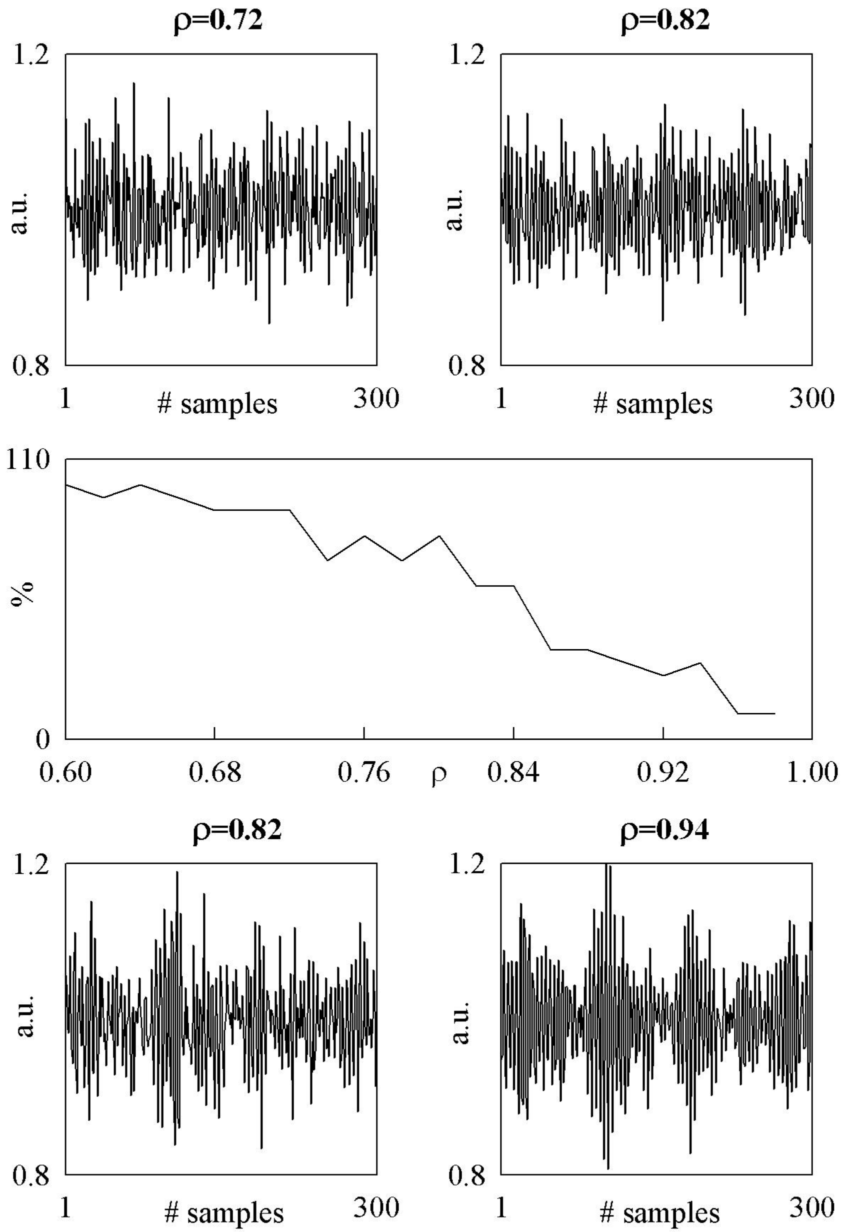
$z=\rho e^{+j\phi}$ and $z=\rho e^{-j\phi}$

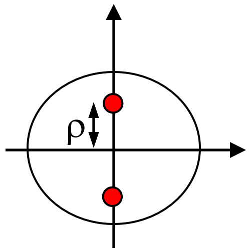
with $\phi=0.25$ and $0.60<=\rho<=0.96$



AR(2) realizations of 2000 samples: 20 sequences of 300 samples drawn at random from each AR(2) realization

Results over type-2 simulation: percentage of stationary segments





Experimental protocol

9 healthy young humans

We recorded ECG (lead II) at 300 Hz

1) at rest (R);
2) during 80° head-up tilt (T80);
3) during controlled respiration at 10 breaths/minute (R10);
4) during controlled respiration at 15 breaths/minute (R15);
5) during controlled respiration at 20 breaths/minute (R20).

The recording duration ranged from 10 to 15 minutes.

Type-1 analysis

The RWS test was applied to a unique sequence of 300 samples per subject (drawn from the entire RR interval series) classified as stationary by visual inspection in a previous study

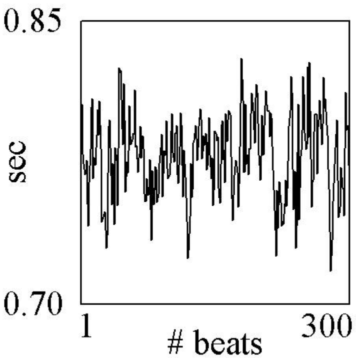
A. Porta et al, IEEE Trans Biomed Eng, 48, 1282-1291, 2001

Aim: is visual inspection made by an expert sufficient to check stationarity?

The percentage of stationary segments was monitored as a function of the experimental condition.

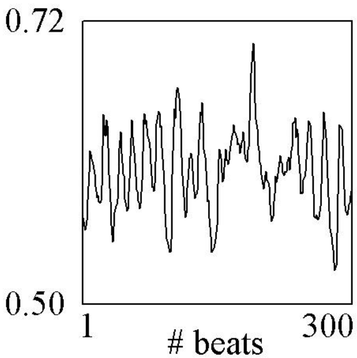
Results of type-1 analysis

Rest



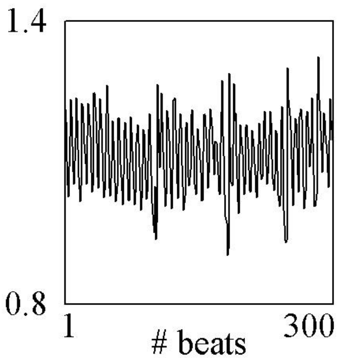
steady mean
steady variance

T80



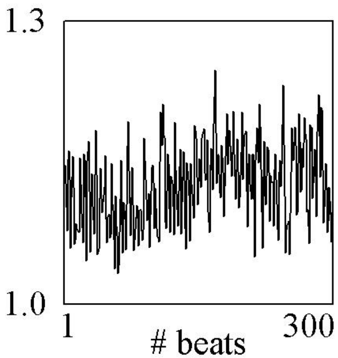
non stationary:
variance changes

R10



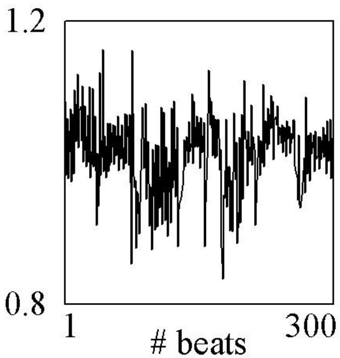
steady mean
steady variance

R15



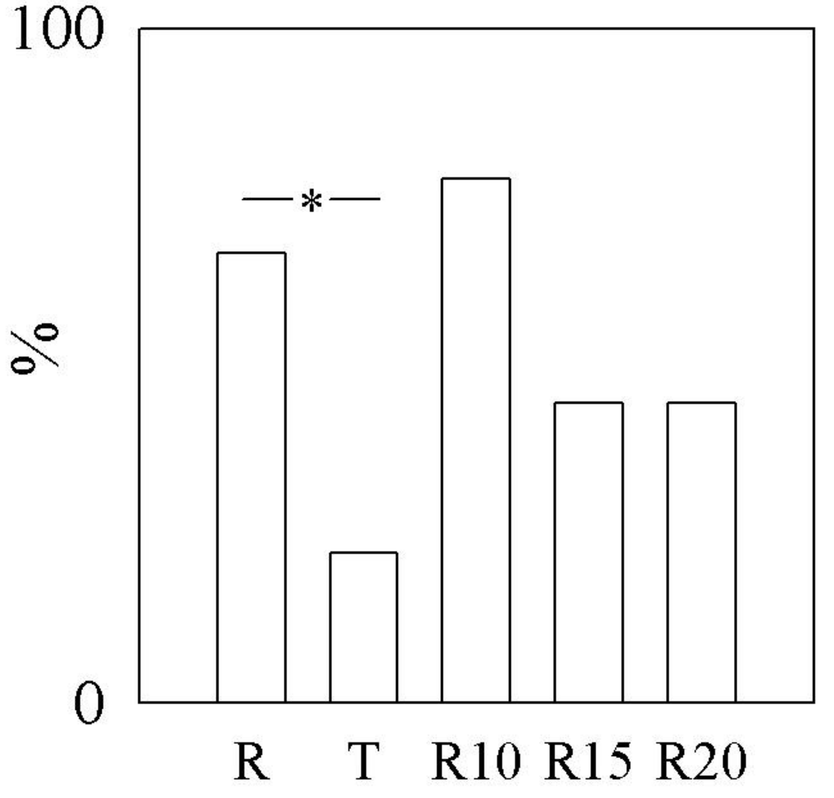
non stationary:
mean changes

R20



non stationary:
variance changes

Results of type-1 analysis



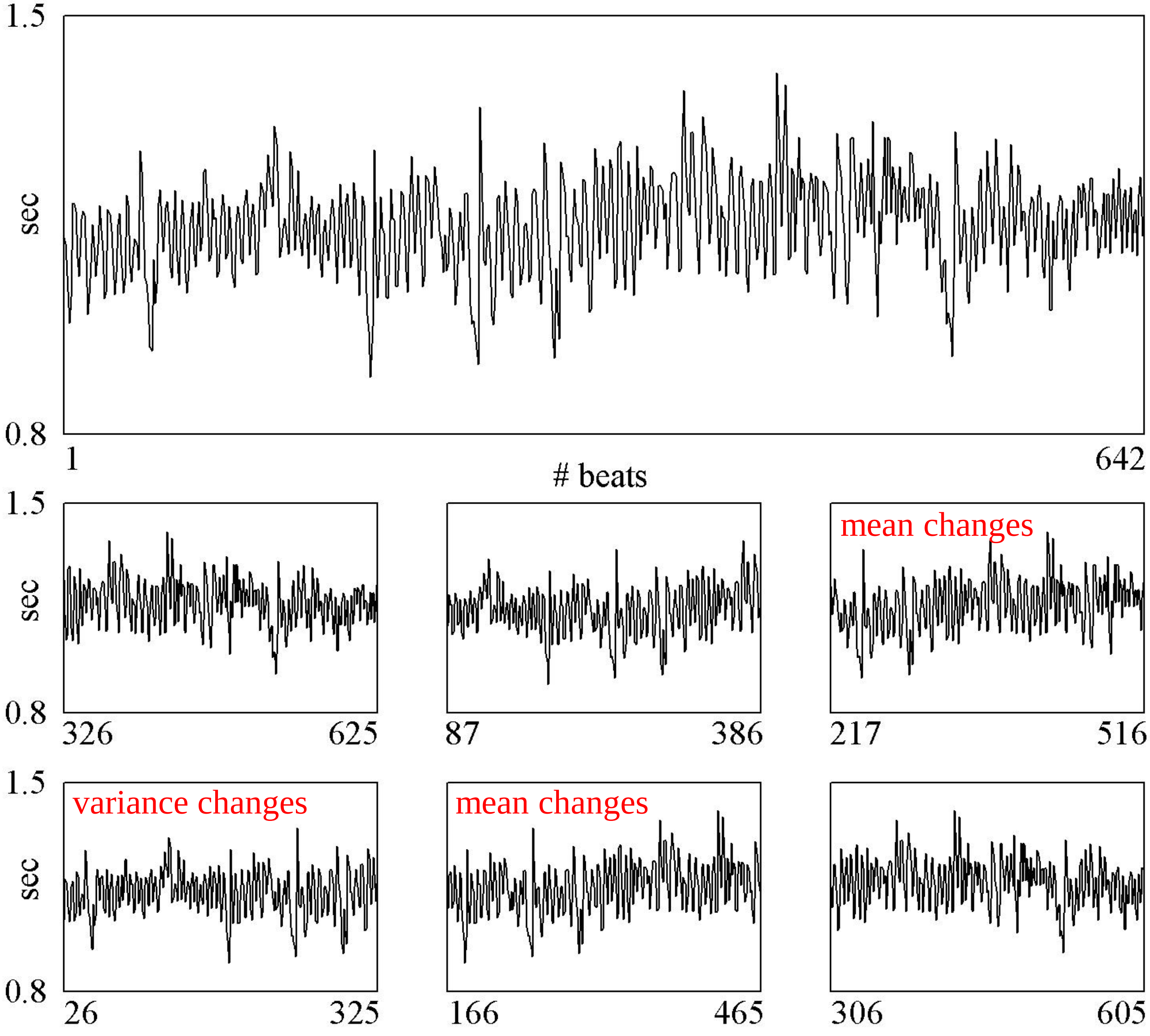
Type-2 analysis

The RWS test was applied to 15 sequences of 300 samples per subject drawn at random from the entire RR interval series

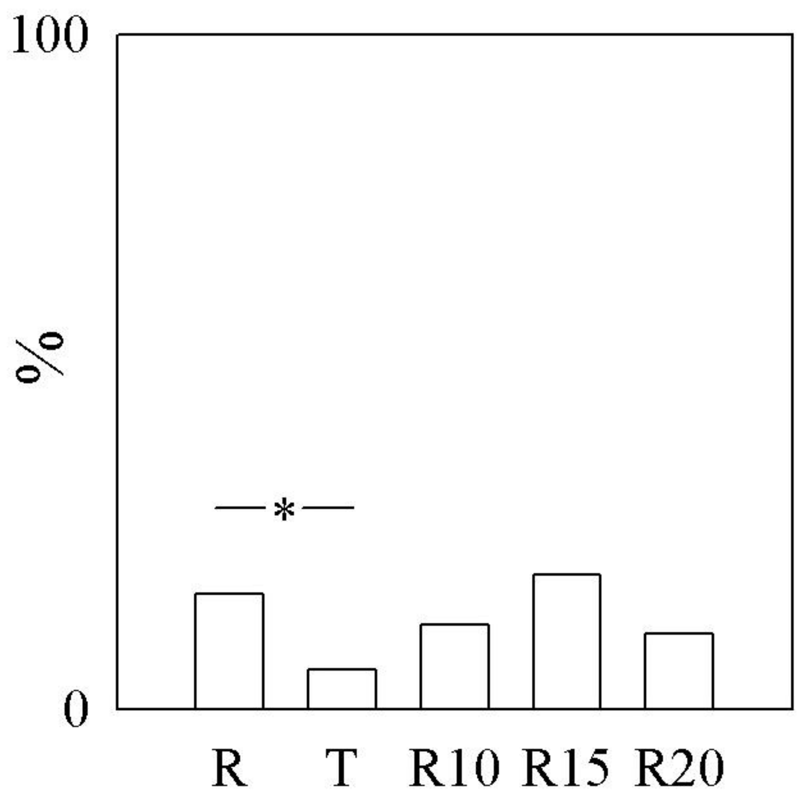
Aim: how easy is to find by chance stationary segments?

The percentage of stationary segments was monitored as a function of the experimental condition

Results of type-2 analysis



Results of type-2 analysis



Conclusions

We propose a test to check the steadiness of mean and variance over short heart period variability series

Stationarity judged by visual inspection may be largely insufficient

Stationary sequences may be difficult to be found even in carefully controlled experimental settings

The difficulty to find stationary periods depends on the experimental condition

Assessing the effects of non stationarities over linear and non linear indexes

The difficulties of finding stationary series prompt for the assessment of the effects of non stationarities over linear and non linear indexes

We computed linear and non linear indexes over sequences (300 beats) extracted from 24h Holter recordings of heart period variability in healthy subjects

Indexes were derived from all sequences with 50% overlap and from the sole sequences classified as stationary

Effects of non stationarities over linear and non linear indexes derived from 24h Holter recordings during daytime

Tab.1 HRV indexes derived from 24h Holter recordings during daytime

Index		all series	stationary series	comparison over the mean	comparison over the variance
LF_{RR}	$[ms^2]$	1349±1217	1624±1440	$p<0.0001$	$p<0.0004$
HF_{RR}	$[ms^2]$	280±439	506±606	$p<0.0001$	$p<0.0001$
LFnu	[%]	80.9±20.9	73.8±27.0	$p<0.002$	$p<0.0001$
HFnu	[%]	18.7±22.7	25.1±26.0	$p<0.001$	$p<0.0004$
0V%	[%]	44.4±13.3	34.4±12.6	$p<0.0001$	
1V%	[%]	40.9±6.8	44.8±4.8	$p<0.0001$	$p<0.0001$
2LV%	[%]	5.8±3.7	8.8±4.3	$p<0.0001$	$p<0.0001$
2UV%	[%]	8.9±6.5	12.0±8.2	$p<0.0001$	$p<0.0001$
CI	[nats]	0.85±0.2	0.99±0.22	$p<0.0001$	$p<0.02$
NCI		0.57±0.1	0.65±0.13	$p<0.0001$	$p<0.01$

Values are expressed as mean±standard deviation.

V. Magagnin et al, Physiol Meas, 32, 1775-1786, 2011

Effects of non stationarities over linear and non linear indexes derived from 24h Holter recordings during daytime

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NCI		0.57±0.1	0.65±0.13	p<0.0001	p<0.01

Values are expressed as mean±standard deviation.

V. Magagnin et al, Physiol Meas, 32, 1775-1786, 2011

Effects of non stationarities over linear and non linear indexes derived from 24h Holter recordings during nighttime

Tab.2 HRV indexes derived from 24h Holter recordings during nighttime

Index		all series	stationary series	comparison over the mean	comparison over the variance
LF_{RR}	[ms^2]	1246±1649	1722±1440	$p<0.0001$	$p<0.0001$
HF_{RR}	[ms^2]	441±519	530±598	$p<0.02$	$p<0.008$
LFnu	[%]	67.5±19.7	69.0±17.9		
HFnu	[%]	32.5±21.0	30.5±17.6		$p<0.003$
0V%	[%]	35.9±16.1	23.9±14.6	$p<0.0001$	
1V%	[%]	42.8±6.9	44.9±6.3	$p<0.0001$	
2LV%	[%]	6.1±4.6	9.5±5.6	$p<0.0001$	$p<0.0004$
2UV%	[%]	15.1±9.3	21.6±11.0	$p<0.0001$	$p<0.002$
CI	[nats]	0.88±0.2	1.00±0.19	$p<0.0001$	
NCI		0.63±0.1	0.72±0.10	$p<0.0001$	

Values are expressed as mean±standard deviation.

V. Magagnin et al, Physiol Meas, 32, 1775-1786, 2011

Conclusions

The presence of non stationarities leads to an overestimation of sympathetic modulation and to an underestimation of vagal modulation

The presence of non stationarities affects the power of statistical tests utilized to discriminate differences among experimental conditions and/or populations