Review of Psychology,
2005, Vol. 12, No. 1, 15-21 UDC 159.9

Dynamics of two psychomotor activities: linear aspects

LJILJANA GREGOV and ANA PROROKOVIĆ

Traditionally, variability in reaction time (RT) is usually interpreted as random error of measurement characterised as stochastic process. However, newer techniques (linear and nonlinear) have indicated that RT series may contain "hidden information" which is neither visually apparent, nor extractable with conventional methods of analysis. The aim of this study was to determine periodical changes in different psychomotor time series: complex reaction time (CRT) series and tapping intervals (TI) time series. A second aim was to examine whether the simultaneous performance of two psychomotor tasks showed interferention and as a result, changed the dynamical structure of underlying processes.

Seven female subjects, aged between 19-25 participated in the experiment. There were five different experimental situations. The experimental design was 2x2 within groups factor experiment, which included 2 levels of CRT task difficulty and 2 task types (single task as well as dual task referring to simultaneous performance of CRT and tapping task). In addition, subjects performed a simple tapping task as alone. The results of this study indicated the existence of some dominant frequencies (periodical changes) in CRT series, as well as in TI time series. Those periodicities could be related to some characteristics of task performance and also, to the exercise and rhythm of breathing. On the other hand, the results of spectral analysis indicated that those time series were not stationary. There was no match found between dominant frequencies in different time segments of CRT and TI time series, which implies difficulties in result interpretation.

However, Gilden et al. (1995) suggested that characteristics of 1/f spectrum could provide much more relevant information than conventional spectral analysis parameters (differentiation of cognitive component and motor component). The results of this study partly agreed with those of Gilden et al., in that the 1/f slopes were non-zero and negative. 1/f spectrum appears to have two components, a flat, white noise component for the high frequencies (motor component), and a negative slope for the low frequencies (cognitive component). Those slopes also depended on the task difficulty. Finally, the results have showed that dynamical structure (linear aspects) of CRT time series didn't change during the simultaneous performance of two psychomotor tasks, while dynamical structure of TI time series changed significantly.

Key words: linear dynamics, psychomotor activity, spectral analysis, 1/f slope

Reaction time is a commonly used measure of cognitive performance that is usually characterized as stochastic. In view of this fact, variability of time reactions is typically assumed to be the consequence of many unknown independent factors. Observed score is assumed to be composed of a true score and an error component. In these earlier studies, variations in performance were explained by the lows of normal distribution and the participation of random, uncontrolled factors. This is contrary to the results of recent studies, which emphasized the deterministic nature underlying different psychomotor processes (Chen, Ding, & Kelso, 1997; Ding, Chen, & Kelso, 2002; Fray & Clayton, 1996; Heath, 2000; Gilden, 1997; Pressing, 1999).

However, there are two major types of analyses for studying time series and testing basic assumption about possible determinism in observed data: spectral analysis (linear approach) and newer nonlinear techniques (Proroković, 2002). Spectral analyses transform the time domain into a frequency domain, and examine the data periodicity. If the series is periodic, then the resulting power spectrum should reveal peak power at the driving frequency. In general, two sources of information are derived from spectral analysis: dynamical structure in the inter-trial fluctuations and individual differences.

Ljiljana Gregov, Department of Psychology, University of Zadar, Krešimirova obala 2, 23000 Zadar, Croatia. E-mail:ljgregov@unizd.hr (the address for correspondence);

Ana Proroković, Department of Psychology, University of Zadar, Krešimirova obala 2, 23000 Zadar, Croatia. E-mail: aprorok@unizd.hr.

Previous studies have shown two types of evidence for dynamical structure in performance fluctuation: short-term linear dependencies and longer-term rhythms. Linear dependencies between sequential responses have been found in various types of psychomotor tasks (Brown & Heathcote, 2004; Cooney & Troyer, 1994; Ding et al, 2002). Furthermore, the passage of time can also lead to systematic dynamics in performance fluctuations. Research have shown the existence of circadian rhythm (Davies & Parasuraman, 1982, according to Kelly, Heathote, Heath, & Longstaff, 2001) and "ultradian" rhythms, such as minute-range periodicities (Makeig & Inlow, 1993) and four-minute periods (Wertheimer, 1953) in different psychomotor tasks.

Analysing dynamics of various psychomotor activities, some authors proposed that the relationship between log spectral power and log frequency of overall and/or certain frequency band could explain dynamics in performance fluctuations (Chen et al., 1997; Frey & Clayton, 1996; Gilden, 1997; Pressing, 1999). They emphasised the fact that a negative relationship (slopes were approximately −1) has been found in a variety of psychophysiological and psychomotor processes.

Gilden, Thornton, and Mallon (1995) assumed that performance of psychomotor tasks has two components. The first component is cognitive, and it is characterised by a negative relationship (approximately -1) between log spectral power and log frequency spanning in range from 0 to 0.1 Hz. Second, the motor component is characterised by a flat slope between log spectral power and log frequency spanning in range from 0.1 to 0.5 Hz. The variance of the later component was assumed to be white noise derived from motor fluctuations and measurement error. The same authors also assumed that the slope of the power spectra depends on the complexity of the task. It should be noted that the tipical 1/f slope (long range correlated) may also occur in non-linear systems which are characterized by a sensitive dependence on initial condition (Kelly et al, 2001).

In line with previous findings, the aim of this study was to determine potential periodical changes in different psychomotor time series: complex reaction time series, and tapping intervals time series. A second aim was to examine whether the simultaneous performance of two psychomotor tasks changes the dynamical structure of underlying processes.

METHOD

Participants

Seven female participants, university students, aged between 19-25 participated in the study. All subjects were right-handed.

Experimental situations

The study consisted of five comparative experimental situations with a duration period of twenty minutes each: CRT task 1 performed as single task, CRT task 1 performed as dual task, CRT task 2 performed as single task, CRT task 2 performed as dual task and tapping task performed as single task.

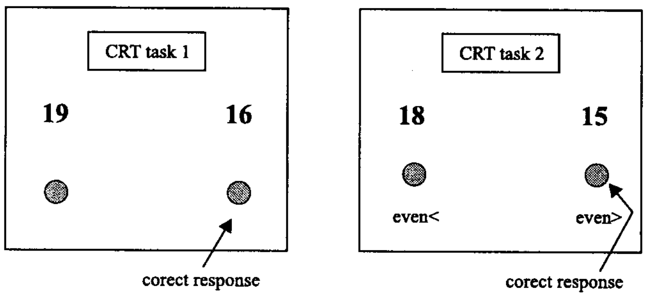
"Dual task" situations included participant's work on two psychomotor tasks simultaneously. The primary task was CRT task, and secondary task was a tapping task. Subjects had to be primarily oriented on CRT task performance, while the tapping task was performed in conjunction with the primary activity. It should be noted that the tapping task was secondary task, i.e. subordinate to the primary task. The time sequence of experimental situations was rotated on a *latin square* principle between subjects.

Tasks description

The tapping task was a simple psychomotor task in which the subject had to "tap" on a computer key (space bar) with his left forefinger (non-dominant hand) according to the subject's own rhythm, as regularly, as he could.

In CRT task 1, the stimulus (two numbers) was presented on the computer screen. One number was a randomly chosen odd number, and the second number was randomly chosen even number (in the range 1-20). The subject was sitting in the front of computer screen, and his task was to press the corresponding key, according to the position of the even number on the screen.

CRT task 2 was more complex then CRT task1. The presentation of stimulus was the same as in the CRT task 1. The subject's task was to react on the right key if the even number was larger then the odd number, or to react on the left key if even the number was smaller then the odd number.



RESULTS AND DISCUSSION

As could be expected, average reaction time and parameters of its variability showed a significant rise with increased memory load in CRT tasks ($F_{(RT,task)}$=119.5, p<.01; $F_{(sdRT,task)}$=45.93, p<.01), but there were no differences in those parameters between independent and simultaneous performance ($F_{(RT,perf)}$=0.5, p>.05; $F_{(sdRT,perf)}$=1.62, p>.05). Furthermore, there were no significant differences in the average time span (means) of tapping intervals between independent and simultaneous task performance ($F_{(TAP,perf)}$=0.4, p>.05). On the other hand, variability (*SD*) of tapping intervals increased significantly during simultaneous performance with each of CRT tasks, in comparison to the independent performance of the tapping task ($F_{(sdTAP,perf)}$=120.13, p<.01).

To determine potential periodical changes in different psychomotor time series, spectral analysis was applied. Examples of spectral analysis for CRT series and TI time series are given on Figure 1 and Figure 2.

The results of the later analysis showed that the most dominant rhythms differed to some extent, between different situations, as well as in relation to the difficulty of CRT tasks. However, most of the dominant rhythms appeared consistent in different participants in the same situations (Table 1). These results indicate that dominant frequencies tend to increase for more complex tasks, especially in a lower frequency band. Comparing the differences between

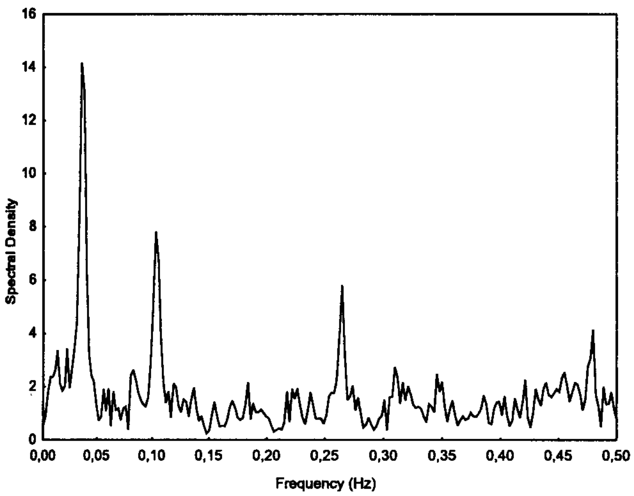


Figure 1. Spectral analysis of CRT series (an example)

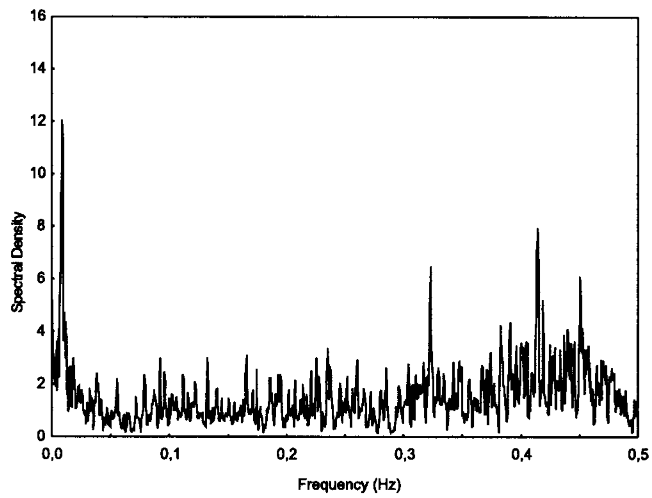


Figure 2. Spectral analysis of tapping intervals (an example)

Table 1

Dominant frequencies (Hz) of CRT series and TI time series in lower frequency band

Subject	CRT SERIES (task 1)		CRT SERIES (task 2)		TI TIME SERIES		
	INDEP.	SIMULT.	INDEP.	SIMULT.	INDEP.	SIMULT. 1	SIMULT. 2
M.J.	.02	.02	**.02**	**.02**	.04	.02	.02
B.B.	**.01**	**.01**	**.02**	**.02**	**.01**	**.04**	.06
A.P.	**.01**	**.01**	.03	.03	.02	.01	**.03**
A.N.	**.01**	**.01**	**.02**	**.02**	**.01**	**.04**	.02
I.R.	**.01**	.02	.01	.03	**.01**	**.04**	**.03**
T.K.	.02	**.01**	**.02**	**.02**	**.01**	.02	**.03**
S.N.	**.01**	**.01**	.01	**.02**	.02	.01	.04
MEAN OF COHERENCE	.64		.62				

Table 2

Dominant frequencies (Hz) of CRT series and TI time series in higher frequency band

Subject	CRT SERIES (task 1)		CRT SERIES (task 2)		TI TIME SERIES		
	INDEP.	SIMULT.	INDEP.	SIMULT.	INDEP.	SIMULT. 1	SIMULT. 2
M.J.	.15	**.25**	.45	.45	.25	.15	**.25**
B.B.	.15	.11	**.25**	**.25**	**.40**	**.40**	.45
A.P.	**.25**	**.25**	**.25**	**.25**	.45	**.40**	.35
A.N.	**.25**	**.25**	**.25**	.45	**.40**	.20	**.25**
I.R.	.11	.11	**.25**	**.25**	**.40**	**.40**	.40
T.K.	**.25**	**.25**	.20	**.25**	.30	.30	**.25**
S.N.	**.25**	**.25**	.45	.45	**.40**	.45	.45
MEAN OF COHERENCE	**.51**		**.56**				

means of reaction times of the two CRT tasks, and differences between observed dominant frequencies of two CRT series in time domain, it seems that the observed rhythmic components (two-minute range period, for example) were the same. It could be possible that the ultradian internal oscillator determined these periodicities. The results also showed that the linear structure of response time dynamic did not change in the course of simultaneous performance of the two psychomotor tasks. The dominant frequencies were the same for both time series (except for two subjects), and the average coherence was 0, 64/0, 62 for lower frequencies. CRT series also included some rhythmic components that were not dominant but important for the explanation of performance fluctuations.

Depending on the tasks demands (task difficulty), the dynamic structure of simple tapping activity changed significantly. Different dominant frequencies were observed in TI time series in the course of simultaneous and independent performance, thus coherences could not been interpreted (Table 2). Changes in dynamic structure of the tapping

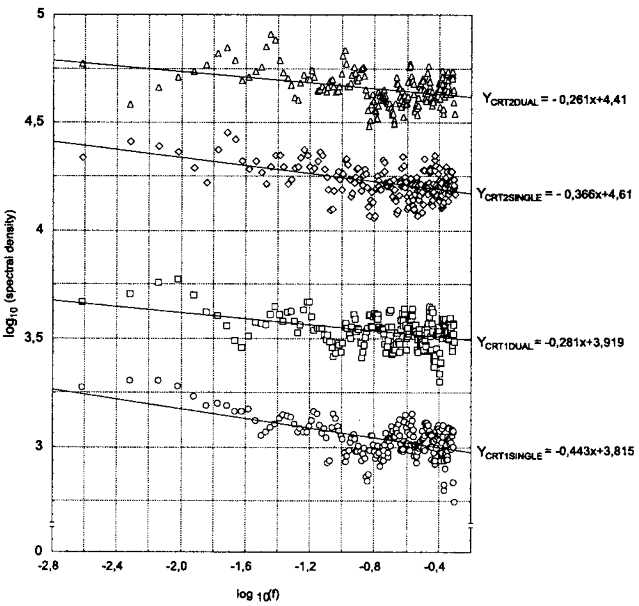


Figure 3. Total 1/f slope for two CRT series (an example)

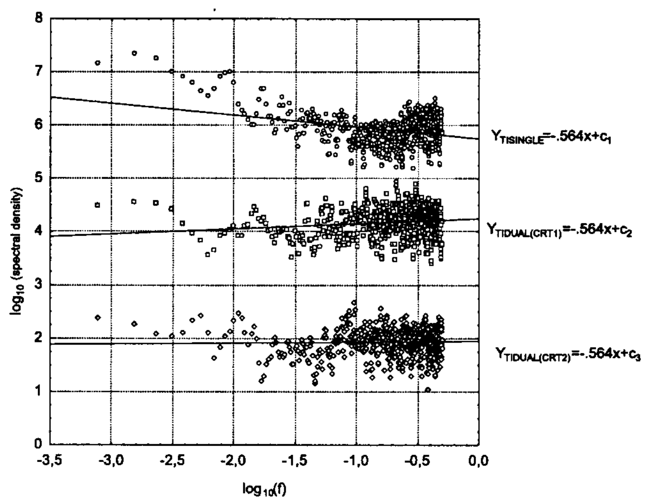


Figure 4. Total 1/f slope for tapping time series (an example)

activity, while the tapping task was performed simultaneously, could be an effect of CRT task performance, on which subjects have been primary focused. Similar results were observed in a higher frequency band, in terms of the effects of task complexity and the type of performance in both CRT series and TI time series. The dominant periodicities on the higher frequency band could be related to some aspects of the task performance (performance rhythm and breathing rhythm).

Further analyses were attempted to determine the effects of task complexity on linear dynamics of psychomotor activity through the relationship between log power plotted against log frequency. According to Gilden et al. (1995), white noise would have a zero slope, while non-random fluctuations would have non-zero slope.

An example of 1/f relationship for CRT series is displayed on Figure 3 and for the tapping time series on Figure 4. The overall slope is a negative non-zero slope. To test

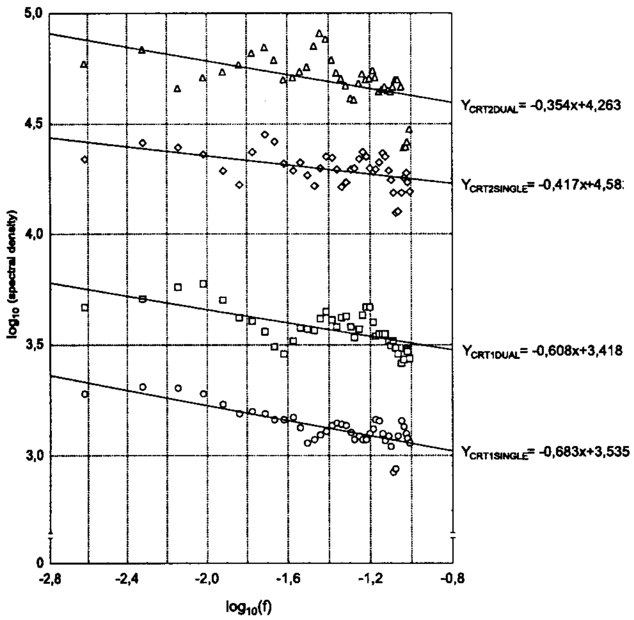


Figure 5. An example of 1/f slope for CRT series (below log *f* equal to -1)

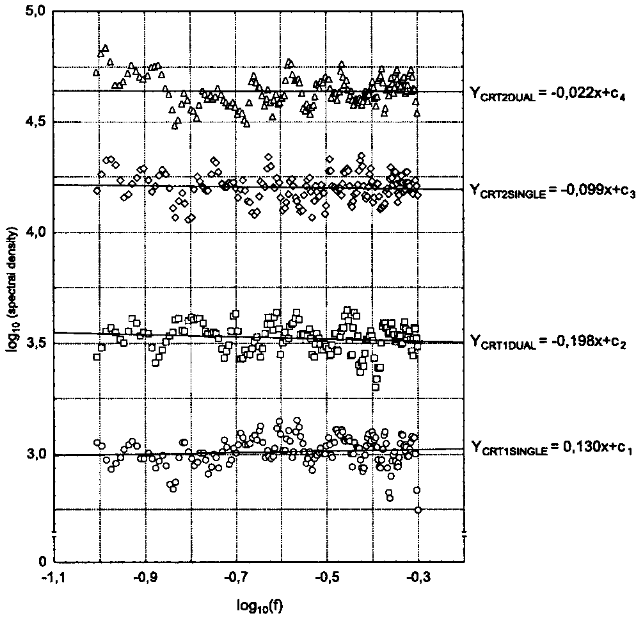


Figure 6. An example of 1/f slope for CRT series (above log *f* equal to -1)

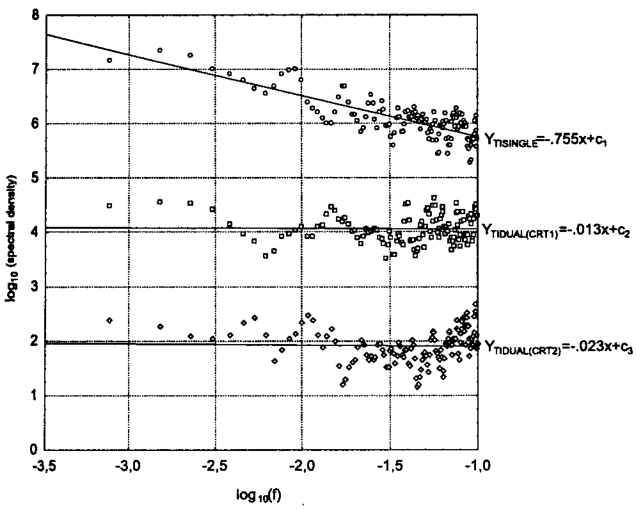


Figure 7. An example of 1/f slope for tapping time series (below log *f* equal to -1)

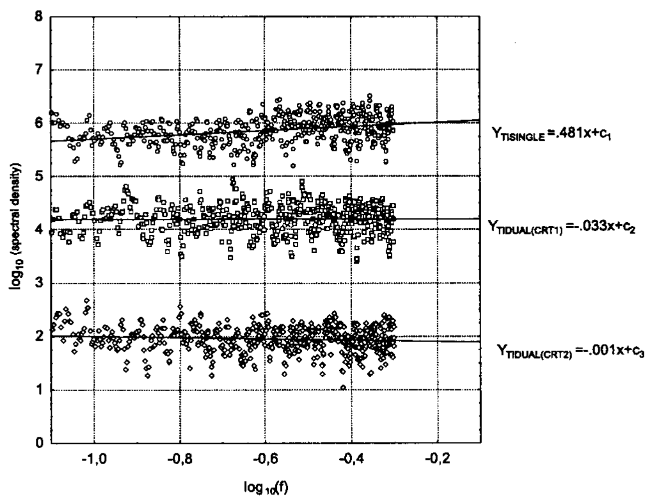


Figure 8. An example of 1/f slope for tapping time series (above log *f* equal to -1)

the significance of the assessed slopes, a standard control analysis of data was applied. Each time series was shuffled randomly. Then, spectral analyses were applied to these shuffled time series. The results showed that the mean and standard deviation of the slopes of the power functions on the shuffled time series were indistinguishable from white noise. 1/f slopes were significantly different from the slopes of each observed time series. These results imply that observed CRT series and TI time series could be deterministic in nature. Most probably, deterministic changes partly originate from a certain linear oscillator, but linear changes could not explain total fluctuation variance, which also includes randomness and possible non-linear determinism.

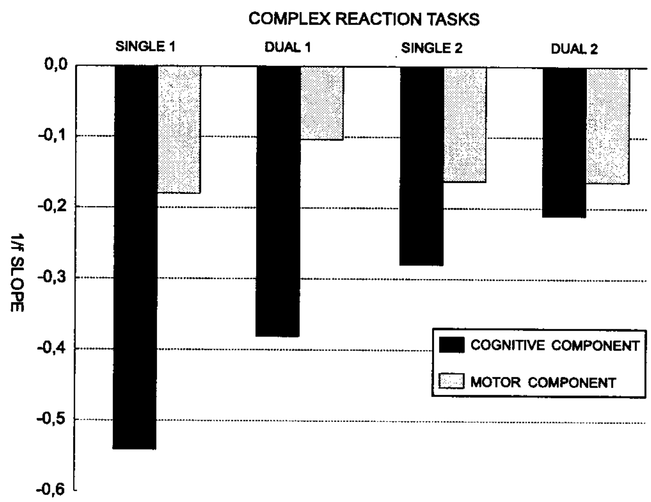


Figure 9. Average 1/f slope lower frequencies (cognitive component) and higher frequencies (motor component) of CRT series

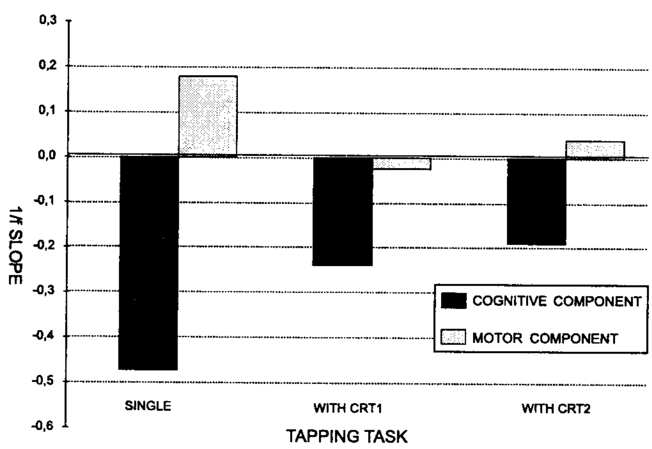


Figure 10. Average 1/f slope lower frequencies (cognitive component) and higher frequencies (motor component) of tapping time series

Figures 5, 6, 7 and 8 show regression line fits for the regions above and below log (frequencies) equal to –1 (examples for CRT series and tapping time series). The location of this criterion point was defined according to Gilden et al. (1995). The slopes for low frequencies were less than one, but still significantly non-zero. On the other hand, slopes for higher frequency band were approximately zero. These results are supported by Gilden et al. (1995), whose model differentiates two major components of psychomotor activity: the cognitive component (an internal clock that mediates the judgment of the passage of time) and the motor component (responsible for executing the response). The first component showed typically 1/f negative non-zero slope, while the motor component usually produced zero slope (white noise).

The results presented at Figures 9 and 10 also indicate that 1/f slope decreases proportionally with the increase of memory load, suggesting that the cognitive component could be determined by a larger number of linear factors (rhythms) for a more complex task. However, these results can also be due to the fact that in complex tasks the power spectrum is increased at 0.1 (Hz) frequency.

Furthermore, there were no differences in slopes of CRT series and TI time series between independent and simultaneous task performance. Despite the fact that different dominant frequencies were observed in TI time series in the course of simultaneous and independent performance, there were no general changes in power spectra on lower frequency band.

The results also indicate that a negative non-zero slope characterized the motor component of complex reaction task, which could be the result of breathing effects (dominant rhythm on the higher frequency band). The motor component of the tapping task (when performed independently) showed positive non-zero slope. This relationship could be explained by a certain linear factor related to some kind of muscle activity, which probably determine the regularity of a simple tapping activity. That linear component was not obtained in TI time series when tapping the task was performed simultaneously with the CRT task.

In conclusion, it could be stated that observed psychomotor activities (CRT series and TI time series) consist both of, randomness and determinism. The dynamic structure of both psychomotor activities is possibly determined by several linear rhythms (i.e. breathing and some ultradian rhythms), and also by task complexity. It seems that the number of linear components underlying psychomotor activity increases with the increase of task complexity.

Finally, the results indicate that linear dynamical aspects of CRT series (primary activity) didn't change during simultaneous performance of two psychomotor tasks, while dynamical structure of TI time series changed significantly (secondary activity).

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