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IDENTIFYING OBJECTIVE DIFFERENCES BETWEEN VOLUNTARY AND INVOLUNTARY MOTION IN BIOMECHANICS

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Abstract. In 1947, N.A. Bernstein hypothesized "repetition without repetition". Therefore, the problem of recording objective differences between voluntary and involuntary movements in biomechanics arises, which was the purpose of these studies. **Materials and methods.** A group of men (age <T> = 27 ± 1.8 YO) was examined according to tremor (involuntary movements) and tapping parameters (voluntary movements). **Results.** Pairwise Comparison Matrices were created for each subject. It was found that for tremor, the number of k samples pairs (which statistically coincided) did not exceed $k_{TR} \leq 5\%$ in these matrices, and for tapping $k_{Tp} \leq 12\%$. **Conclusion**. All the matrices for all the subjects showed the lack of statistical stability of the samples (for both tremor and tapping). This is the proof of N.A. Bernstein hypothesis and the Eskov – Zinchenko effect. However, the k_{Tp} number is always 2–3 times greater than the k_{TR} number, which is an objective assessment of the differences between voluntary (tapping) and involuntary movement (tremor).

Keywords: *tremor, tapping, pairwise comparison matrices, Eskov-Zinchenko effect.*

Introduction. Over the past 50–60 years, a discussion about the objective assessment of voluntary and involuntary movements in biomechanics has repeatedly arisen [1, 2, 7, 10, 14, 15]. This problem became even more acute after the proof of Bernstein's "repetition without repetition" [3, 11–13, 16–20] and the Eskov – Zinchenko effect in the form of statistical instability of tremorograms (TMG) and tappingrams (TPG). This Eskov – Zinchenko effect questioned the further use of traditional statistical methods in biomechanics [2, 4–9, 8–13].

Obviously, in the light of the Eskov – Zinchenko effect, it is necessary to develop new methods and models for describing both voluntary movements (tappingrams) and involuntary movements (tremorograms). This is explained by the fact that any sample of tremorograms and tappingrams can be unique. It has no repetitions in biomechanics. One of such promising methods for assessing movements is the method of Pairwise Comparison Matrices. Such matrices contain the k numbers of pairs (tremorograms or tappingrams) that can have one common general population. It turned out that these k numbers can characterize the physiological state of the subject. Here we use this matrix calculation method to objectively assess the differences between tremorograms and tappingrams.

Materials and methods. A group of 15 males (average age <T> = 27 ± 1.8 years) was repeatedly subjected (15 times for each subject) to tremorograms (in a calm state, sitting) and tappingrams recording for the index finger. In this case, a patented recorder based on eddy current sensors was used, which ensured the accuracy of recording for the position of the finger along the vertical axis of at least 0.1 mm ($\Delta x \leq 0.1$ mm). Tremorograms and tappingrams recording was carried out for the time interval of $\Delta t = 5$ s. The analog signal was quantized (quantization period $\tau = 10$ ms) so that in each sample of tremorograms or tappingrams there were at least 500 points (the $x_1(t)$ coordinate vertical position of the finger).

For each subject, 15 samples of tremorograms and tappingrams were obtained. As a result, matrices of pairwise comparisons of these samples were constructed, in which the number k of samples pairs were determined where the Wilcoxon criterion p was $p \geq 0.05$. In this case, such a pair could have one common general population. These pairs (k_{TR} for tremorograms and k_{TP} for tappingrams) were compared for each subject.

Results. Pairwise Comparison Matrices of tremorograms showed that the number of k_{TR} pairs of samples coincidences for all 15 subjects is very small, usually $k_{TR} \leq 5\%$ (for all 105 independent pairs in each matrix). This proves Bernstein's "repetition without repetition" hypothesis.

The share of stochastics is extremely small in all 105 different pairs of TMG comparison. The remaining 95% of couples do not have a common population, i.e. they are not statistically the same. This is also proved by the Eskov – Zinchenko effect.

The Eskov – Zinchenko effect shows no statistical stability of samples, each sample of tremorograms is unique. Let us emphasize that the possibility of pairs statistical coincidence (registered in a row) is generally inappreciable. The probability p_{TR}^2 of such a match is usually $p_{TR}^2 \leq 0.01$. Any sample of tremorograms is unique, and the proportion of stochastics is extremely small. To compare, we present a Table 1, where the number $k_{TR} = 3$, i.e. here the share of stochastics is less than 3%.

The result is different for voluntary movements. Table 2 shows representative Pairwise

Table 1

Tremorograms Pairwise Comparison Matrices of the same person, Wilcoxon test ($p < 0.05$, number of matches $k_{TR} = 3$)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		0,00	0,00	**0,22**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	0,22	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	0,00	0,00	0,00	0,00		**0,72**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	0,00	0,00	0,00	0,00	0,72		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	**0,51**	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,51	0,00		0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	

Table 2

Tappingrams Pairwise Comparison Matrices of the same person, Wilcoxon test ($p < 0.05$, number of matches $k_{TR} = 13$)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		**0,28**	0,00	**0,33**	0,00	**0,88**	0,01	0,00	0,00	0,00	0,00	0,02	0,00	0,01	0,00
2	0,28		**0,31**	0,00	0,00	0,00	**0,52**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**0,07**
3	0,00	0,31		0,00	0,00	0,00	**0,32**	0,01	0,00	0,00	0,00	0,00	0,00	0,00	**0,22**
4	0,33	0,00	0,00		**0,09**	**0,84**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	0,00	0,00	0,00	0,09		0,03	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00
6	0,88	0,00	0,00	0,84	0,03		0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,03	0,00
7	0,01	0,52	0,32	0,00	0,00	0,00		0,01	0,00	0,00	0,00	0,00	0,00	0,00	**0,34**
8	0,00	0,00	0,01	0,00	0,00	0,00	0,01		0,00	0,00	0,00	0,00	0,00	0,00	0,01
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,04	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,04		0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	**0,76**	0,00	0,00
12	0,02	0,00	0,00	0,00	0,01	0,02	0,00	0,00	0,00	0,00	0,00		0,00	**0,26**	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,76	0,00		0,00	0,00
14	0,01	0,00	0,00	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,00	0,26	0,00		0,00
15	0,00	0,07	0,22	0,00	0,00	0,00	0,34	0,01	0,00	0,00	0,00	0,00	0,00	0,00	

Comparison Matrices of tappingrams samples. Here, the pairs number of k_{Tp} samples of tappingrams, which can have one common general population, is significantly greater than the number of k_{TR} in Table 1. Usually, the value of k_{Tp} is 2–3 times higher than for tremorograms.

This pattern is typical for all tremorograms and tappingrams matrices when they are compared by the k parameters, i.e. the number of pairs of samples for which $p \geq 0.05$. It is obvious that active consciousness intervention in oscillatory movements of the subject's finger (against its involuntary tremor during postural tremor, see Table 1) severely changes the share of stochastics. In a number of matrices, k_{Tp} reaches 15% off all 105 pairs of tappingrams samples comparison. However, it is still a small value.

Statistically comparable samples are obtained with a probability $p \geq 0.95$ in stochastics. For example, these are the requirements for the confidence level, but we have $p \leq 15$ %, which is a very small value. Let us note that 15 different subjects (during tremorograms and tappingrams recording) will show the samples' Pairwise Comparison Matrices very similar to Table 1 (for tremorograms) or Table 2 (for tappingrams). In other words, the samples of tremorograms or tappingrams of different subjects will not statistically coincide, i.e. we observe the Eskov – Zinchenko effect for the group. In fact, this is the loss of homogeneity in the group of subjects

Conclusion. Any parameters of tremorograms or tappingrams (both for one subject in the n = 15 repetitions mode, and for a group) show statistical instability of tremorograms or tappingrams samples.

This got the name of the Eskov – Zinchenko effect In biomechanics, the Eskov – Zinchenko effect proves Bernstein's "repetition without repetition". Because of this effect a significant problem arises in the analysis of tremorograms or tappingrams within stochastics. How can a change in the NMS state be registered if, in an unchanged physiological state (with repeated measurements), the samples of tremorograms or tappingrams are continuously and chaotically changing? To solve this complicated situation, it is proposed to calculate the samples' Pairwise Comparison Matrices. It turned out that the number of k_{TR} pairs of samples ($p \geq 0.05$) for tremorograms is always less than k_{Tp} for tappingrams.

While performing voluntary movements human consciousness increases the share of stochastics ($k_{Tp} > k_{TR}$). However, in any case, the statistical chaos of the tremorograms and tappingrams always prevails over stochastics. All samples are unique, and the possibility of neighboring samples coincidence (recorded in a row) is extremely small ($p_{TR}^2 \leq 0.01$, $p_{TR}^2 \leq 0.02$). All this limits the possibilities of stochastics further use in assessing the organization of movements and physiology of the NMS in the whole. New models and new methods of motion analysis are needed.

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ИДЕНТИФИКАЦИЯ ОБЪЕКТИВНЫХ РАЗЛИЧИЙ МЕЖДУ ПРОИЗВОЛЬНЫМИ И НЕПРОИЗВОЛЬНЫМИ ДВИЖЕНИЯМИ В БИОМЕХАНИКЕ

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В 1947 году Н.А. Бернштейн выдвинул гипотезу о «повторении без повторений». В этой связи возникает проблема объективной регистрации различий между произвольными и непроизвольными движениями в биомеханике, что и составило цель настоящих исследований. **Объект и методы.** Обследовалась группа мужчин (средний возраст <*T*> = 27 ± 1,8 года) по параметрам тремора (непроизвольные движения) и теппинга (как произвольные движения). Траектория движения пальца испытуемого при треморе и теппинге регистрировалась как набор дискретных точек, для которых (после 15 повторов) строились матрицы парных сравнений выборок. **Результаты.** Для каждого испытуемого была построена матрица парных сравнений выборок и было установлено, что для тремора в этих матрицах число пар k выборок (которые статистически совпадали) не превышает $k_{TR} \leq 5$ %, а для теппинга $k_{TP} \leq 12$ %. **Выводы.** Все матрицы для всех испытуемых показали отсутствие статистической устойчивости выборок (как для тремора, так и для теппинга). Это доказывает реальность гипотезы Н.А. Бернштейна и эффект Еськова – Зинченко. Однако число k_{TP} всегда в 2–3 раза больше, чем число k_{TR}, что и является объективной оценкой различий между произвольным движением (теппингом) и непроизвольным движением (тремором).

Ключевые слова: *тремор, теппинг, матрицы парных сравнений, эффект Еськова – Зинченко.*

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