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Original article

STUDY ON THE NEUROMUSCULAR CONTROL ASSESSMENT BY USING THE CARTESIAN MOTION ANALYSIS

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Abstract*

Aim. The purpose of this paper is to highlight the opportunity of assessing neuromuscular control by the Cartesian motion analysis, based on the coordination component of motor ability, namely precision. Thus, we aim to check the appropriateness of computerized neuromuscular control assessment by investigating precision-related benchmarks when ultra slow motions are performed by the upper limbs at a constant speed of 10mm/s.

Methods. As research methods, there were used: bibliographic study, observation, Cartesian motion analysis, statistics. In order to track the Cartesian motion, a computer platform, Kinect X Pro 1.0, was designed and programmed. The platform uses a Kinect 2.0 motion analyzer that provides the subject executing the movement with real-time feedback about the performance parameters (speed, direction, deviations in both the left and right hands).

We conducted calibration and verification tests on a group of 22 subjects, of whom 2 active athletes (with national and international medals), 7 athletes withdrawn from activity (5 with national and international medals) and 14 non-athletes, aged between 23 and 39 years. In addition, it was carried out a comparative testing with given algorithm between an athlete and a non-athlete, for the coordination parameters depending on the type of effort (anaerobic alactacid and lactacid) and the use or lack of visual control. Different testing frequencies (from over 5 assessments/second to less than one assessment per second) were used.

Results. The first sets of tests showed a loss of homogeneous distribution in average speed per testing unit, when the testing unit duration was reduced, and an increasingly higher range in the quartile variation compared to the target. Comparative testing supported the initial observations for the two effort intervals assessed.

Conclusions. Tracking the motion per very short time intervals highlights a real difficulty in maintaining a constant speed in the motor actions of upper limbs, although, apparently, it looks like a continuous, smooth motion with constant speed. The observation is most likely an outcome of the complex coordination of muscle contractions and emphasizes not a basal, but a secondary character of speed (as human motor ability) resulting from a coordinated composition of equal forces.

Keywords: Cartesian analysis, precision, coordination.

Introduction

Motor ability, through its three conditional components (strength, speed, endurance), is another topic generating conceptual and implicitly practical, training-related controversies. Not long ago, dexterity was considered a component of conditional abilities, too. For this reason, also with reference to the ways of assessing these crucial components of sports performance, it is noted the permanent concern of specialists with identifying new viable measurement tools.

The spectacular developments in technology (particularly regarding the highly accurate assessment of motion for very short time intervals) allow nowadays a refined phenomenological analysis and a repositioning of these components depending on the background layer.

Initial analysis targeted to the slow, very slow and super slow workouts (Mercola, 2016) used today especially in the United States to develop muscle strength and endurance, but also quite popular in the virtual information environment.

Ken Hutchins (see Hutchins, 1989, 1992) is considered the inventor and promoter of super slow exercises as early as the 80s. These motions are executed at a speed of about 100 mm/s (10 cm/s), with submaximal, sometimes very small weights (10% of the maximal weight used), requiring increased neuromuscular control in performing the motor action.

An example of such a super slow exercise is from sitting or lying on the back, hands to shoulders, palms extended in pronation, fingers pointing up and thumb in abduction, slowly stretching the arms upward or forward-upward for 10s, followed by slow return to the initial position in the next 10s. During the exercise, several breathing cycles occur (Dauphin, 2009).

In the case of slow exercises, a prolonged breathing cycle is achieved (Mercola, 2012). In both situations, the demand is considerably strong, and the checkpoint for exercise efficiency is the sensation of exhaustion, nervous breakdown, “Cannot stand it anymore”.

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Studies on neuromuscular control were conducted, in our country, within the National Institute for Sport Research, by a team of researchers under the coordination of Pierre de Hillerin (Hillerin, Schor, Stupineanu, 1985).

According to Hillerin (1999), in the motor control area, there are included the "borderline phenomena" of motricity (both the voluntary and reflex ones), as well as the way in which it would be possible for them to shift temporarily from the unconscious control path to that of conscious adjustment, in order to increase the efficiency of movement. To objectify this phenomenon, there were perfected the Ergosim conditions simulators, whose popularity has progressively increased among practitioner specialists.

The terminology used for this category of movements is not systematically unitary, sometimes slow and very slow motions being referred to as super slow, while a clear prioritization, according to speed, seems not to be available in the specialized literature. For this reason, we propose the following classification:

a. slow and very slow exercises: made up of motor acts performed at speeds of over 15 cm/s, correlated with inspiration, expiration or a full breathing cycle.

b. super slow exercises (according to Hutchins): made up of motor acts performed at speeds of 10±8 cm/s, correlated with several full breathing cycles.

c. ultra slow exercises: made up of motor acts performed at speeds between 0.5 and 2 cm/s, correlated with several full breathing cycles.

We believe that ultra slow motions executed at a constant speed, whose precision is reflected in an increased efficiency of the action, also fall within the neuromuscular control area, where the performer is aware of both each intermediate movement position and the transition from one position to another, and the gradual development of the action. Moreover, these movements involve an increased voluntary control, the performer being focused on removing the segment oscillations or deviations from the established trajectory.

Through the ultra slow exercises, it has been attempted to extend the type of slow-motion training towards the possible lower limit of continuous motion that a subject fit for physical exercise, without disabilities, can perform. The idea of this type of training has started from the general practice framework, which is observed by the exercises from Ergosim training system (constant speed, established strength conditions for testing, range of motion conditioned by an ideal motion model). The possibility to become aware of the segment positioning and oscillations throughout the duration of a slow motion remains secondary, attention being primarily focused on the real-time superposing of graphs on the computer screen and searching for solutions to control the required parameters. Sometimes, the athletes who use for practice, as a complementary training method, the computerized Ergosim system, are more concerned about the score

awarded by the computer for their execution than the correction of movement from one repetition to another (Urzeală, 2008).

In this context, the challenge for this study was to identify a way of increasing the movement precision, as a component of coordination abilities, and its persistence over time by training the coordinating cortical motor center, with or without visual feedback, either of one's body while performing the action or cognitive feedback (resembling the Ergosim system), without external loads in terms of force or with very reduced loads (maximum 0.5kg). It is well known today that motor cortex fatigue appears before muscle fiber fatigue (Cunningham, 2016; Scand, 2015; Enders, 2016).

The purpose of this paper is to highlight the opportunity of assessing neuromuscular control by the Cartesian motion analysis, based on the coordination component of motor ability, namely precision. Thus, we aim to check the appropriateness of computerized neuromuscular control assessment by investigating precision-related benchmarks when ultra slow motions are performed at a constant speed of 10mm/s.

The difficulty in maintaining movements at a constant speed, much below (v=10±5mm/s) what is used today as variants of practice in sports training, has generated the research and implementation of specific training to improve this ability by means of USMIT – Ultra Slow Motion Intelligent Training (Rădescu, 2016).

Methods

Participants

The sample was made up of 22 subjects aged between 23 and 39 years (mean: 26.59, standard deviation: 5.05), with different athletic background (athletics, tennis, fencing, football, martial arts, swimming, dancesport, artistic gymnastics, mountain climbing) and various competitive achievements (14 recreational athletes and former athletes, 7 former performance athletes, 2 performance athletes, medalists or not at the national and international levels), who participated in an initial assessment (IA).

Among them, it was selected a group of three subjects with a particular athletic history, the specificity of their sports branch requiring good neuromuscular control and increased precision, for which a detailed secondary assessment (SA1) was conducted. Only one of the three subjects followed a

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specific training program, part of USMIT, over a 5-month period, being assessed repeatedly and participating in the final secondary assessment (SA2). Table 1 shows details about the three participants in the secondary assessment.

Table 1. Information about the participants in the secondary assessments (SA)

	Age	Sport	AT Shape*	Environment	Status**	Pulse R/As	VR	Hours of Max***	Gender
S1 P	*39*	*Tennis*	*3*	*U*	*RA*	*64/72*	*0.13 s*	*17:30-19:30*	*M*
S2 M	24	Tennis	4	U	FPA	63/75	0.08 s	17:00-18:00	M
S3 A	36	Dance	3	U	RA	68/78	0.11s	20:00-22:00	F

* athletic shape, self-assessment on a scale from 1 to 6; 6 – best value
** athletic status: former performance athlete (FPA), recreational athlete (RA)
*** circadian peak interval from the physical and mental points of view

Devices and materials

As research methods, there were used: bibliographic study, survey method (to select the largest possible range of sports activities), observation (direct and immediate phenomenological analysis, computerized motion analysis, phenomenological analysis of the reactions during testing and immediately after testing), experiment (the training component, part of USMIT), case study (both the cross-sectional, IA and SA1, and longitudinal one, for the training impact and SA2), and also statistical analysis methods (MS Office Excel 2014 and Epi2000).

The devices used were: Kinect X Pro 1.0 (a computerized system for the Cartesian motion analysis, on a Kinect 2.0 support developed in collaboration with Brains Software and R. Barn Foundation for Medicine and Health), digital timer (Stopwatch application, IPhone 4, OS 7.1.2), pulse oximeter (Prince-100C Fingertip Oximeter) and other peripheral devices (tripod, linear meter, etc.).

Based on the preliminary studies of USMIT program, this study analyzes the appropriateness of framing speed among the conditional motor abilities (along with strength and endurance), by investigating precision-related benchmarks when ultra slow motions are performed at a constant speed of 10±5mm/s, as part of the purposely-designed special training. For the analyzed component, there were recorded the motions in the distal extremities of upper limbs (the palms).

Preliminary testing (on a group of 22 subjects with different athletic background) has shown that although, apparently, at a subjective assessment with the naked eye, it is possible to perform smooth motions at a constant speed reaching the limit of super slow motions (10mm/s), in the case of an objective assessment with the computerized Kinect X Pro system, it is revealed a clear variation in average speed, in the mode, for short time intervals ($0.11s<\Delta t<0.33s$).

Selection of subjects

The initial group (IG) was assigned, as previously mentioned, to perform the largest possible range of sports activities, as a personal experience of the subjects with and without sports performances at the national and international levels, still active or withdrawn from activity, canalized towards the sports for all. Participation of subjects was done on a voluntary basis.

The secondary group (SG) was made up by selecting from the IG two sports activities recognized as requiring a high degree of precision and speed in coordination (tennis and dance).

For tennis, there were selected two subjects, one with previous performance activity and the other as a recreational player. They were joined by a participant practicing Argentinian tango as a leisure activity, with a past motor experience of 12 years in rhythmic gymnastics. It was thus made up the study group SG1 (three subjects), within which one subject (S1, Table 1) followed a training program with 5 sessions per week and a duration of 15-20 minutes per day, consisting of ultra slow motions (the basic component of USMIT), over a period of 5-calendar months (November 2013 - March 2014). During that period, other forms of training were suspended (in our case, tennis training). It was thus made up the study group SG2 (one subject, a case study with experimental intervention). For SG2, regular tests were conducted at different times of the day, tracking the following: pulse at the initial testing moment, number of sleep cycles for the previous night, results in three adapted tests assessing the reaction speed and anticipatory reaction speed.

Procedure for achieving the assessments

1. Initial assessment (IA) was carried out in two stages, the group being divided into two

subgroups that were tested in the same time interval (15:00-18:00), using the same algorithm to present the testing and for the testing itself.

There were tracked the following parameters: pulse at the initial testing moment, results in three adapted tests assessing the reaction speed and anticipatory reaction speed, results in two precision and coordination tests:

a. TP1 – testing the ability to maintain a fixed position of palms (from seated on a chair, hands to shoulders, palms in pronation, fingers stretched and close together, thumb in abduction), without visual control, for the intervals: I1 (0-15s), I2 (21-50s) and I3 (0-50s) from the testing duration of 1 minute;

b. TP2 – testing the ability to execute a slow action of the arms, their stretching forward-upward from the position described above, at a constant speed, with an amplitude of 30-40 cm, tracking the palm oscillations, followed by a downward movement to regain the initial position, with visual control, but without computerized feedback, for the intervals: I1 (0-15s), I2 (21-50s) and I3 (0-50s) from the testing duration of 1 minute;

The precision of data recording was adjusted to 9 assessments per second, removing 10% of the extreme values obtained.

2. The first secondary assessment (SA1) was conducted individually for each subject, using the same algorithm to present the testing and for the testing itself.

There were tracked the following parameters: pulse at the initial testing moment, results in three adapted tests assessing the reaction speed and anticipatory reaction speed, results in six precision and coordination tests, for the intervals: I1 (0-15s), I2 (21-50s) and I3 (0-50s) from the testing duration of 1 minute:

a. TP1.1 – testing the ability to maintain a fixed position of palms (from seated on a chair, hands to shoulders, palms in pronation, fingers stretched and close together, thumb in abduction), with visual control;

b. TP1.2 – testing the ability to maintain the same fixed position of palms, without visual control;

c. TP1.3 – testing the ability to execute a slow action of the arms, their stretching forward-upward from the position described above, at a constant speed, with an amplitude of 30-40 cm, tracking the palm oscillations, followed by a downward movement to regain the initial position, with visual control, with computerized feedback.

The precision of data recording was adjusted to 9 assessments per second (Δt=0.11s).

Testing was performed again (TP2.1, TP2.2, TP2.3) at a precision of 3 assessments per second (Δt=0.33s). There were also obtained several recordings with an assessment interval exceeding 0.33s.

For all six testing stages, 10% of the extreme values obtained were removed.

3. The second secondary assessment (SA2) was achieved by repeated testing over a period of 10 days, for the subject S1. The tests used were for the same intervals: I1 (0-15s), I2 (21-50s) and I3 (0-50s) from the testing duration of 1 minute, just as for the IA. The precision of data recording was adjusted to 9, respectively 3 assessments per second (TP2.1, TP2.2), removing 10% of the extreme values obtained for both testing phases.

Training procedure

It was followed by a single subject participating in the initial testing.

Training was performed at least 5 times per week, over a 5-month period, in the morning, immediately after waking up, the practice lasting 15-20 minutes and being applied after the preliminary tests for motion calibration at a constant speed (through timekeeping and correlation with the breathing cycles). Exercises included in the program were the following:

A1. In the supine position, pushing from the chest a weight of 0.5kg per hand, with bilateral coordination of movement (maintaining a distance of 10 mm between forefingers and thumbs of the left hand and right hand respectively), with a constant target speed of 10 mm/s, on an upward and downward trajectory, with repetition for 8-10 minutes (4-5 reps).

A2. “The bicycle” (performing a movement that imitates cycling as well as possible, by observing the circular trajectories and also the distances and directions of motion), with a circular travel speed as low as possible (either four breathing cycles for a full circulatory movement or eight; about 4 or 8 rotation cycles per minute, on average 3 cycles anteriorly and 3 cycles in the opposite direction).

A3. Squats, with foot soles parallel and planted to the ground, hands crossed anteriorly, executed with a speed as constant as possible in bending and stretching the knees, with a length of 60(±5) seconds and a maximal femoral-tibial flexion angle of 30°(±5).

Exercises A1 and A2 were performed systematically during the 5 months of training. Exercise A3 was performed starting with the fourth month of training.

Results

Regarding the initial assessment (IA), none of the participating subjects (IG) managed to achieve a harmonious, continuous movement at a constant speed of 10mm/s or a static position. Even more than that, the variation in average speed, in the mode, per analysis time unit (Δt=0.11s) for the constant-speed movement test (TP2) showed an inhomogeneous variation, with coefficients of variation over 0.35 (35%) and an average coefficient of variation, minimal for the right hand, the anaerobic alactacid interval, I1 (0-15s). Under these circumstances, an indicator of variation in average speed, in the mode, was the median quartile. Minimal average value of the quartile was 6.8±1.52 mm/s, also for the right hand (see Table 2), while the median value fluctuated between 4-18mm/s (see Fig. 1). There were conducted tryouts for some subjects, in order to calibrate the Kinect X Pro assessment system. Subsequently, it has been brought to the forefront, obviously, the fact that increasing the testing interval of the assessment system, from Δt=0.11s to Δt=1.33s, led to a decrease in the coefficient of variation, under 0.35 (35%) for the left hand, for all three intervals of effort analyzed (0-15s/15-50s/0-50s), which would represent a degree of homogeneity for the obtained values of average travel speed (in the mode). Interpreting conversely the analyzed data, a decrease in the time interval between Cartesian assessments leads to increased variation in average travel speed, in the mode, between the two Cartesian points for which the analysis is made.

Table 2. Statistical indicators for the initial assessment (IA)

	Left hand		Right hand	
	Mean value	Std. Dev.	Mean value	Std. Dev.
Coef. Var. 0-15	0.515	0.117	0.458	0.086
Coef. Var. 21-50	0.531	0.254	0.509	0.157
Coef. Var. 0-50	0.548	0.253	0.505	0.127
Quartile 0-15	7.36	2.19	6.8	1.52
Quartile 21-50	8.32	2.35	7.64	1.95
Quartile 0-50	7.84	1.67	7.36	1.86

For the first secondary assessment (SA1), bearing in mind the low number of tests carried out, 18 tests (six for each of the 3 subjects assessed), it was confirmed the tendency to reduce the coefficient of variation in average speed, the achieved values being under 0.35 (35%) in 33% of the 54 values obtained with determinations at intervals of more than 0.33s, compared to 0% in the other 54 values obtained with determinations at intervals of 0.11s.

For the second secondary assessment (SA2), there were carried out 64 determinations on a single subject, within a 10-day period, of which 32 assessments TP1.1 and 32 assessments TP1.2, 50% of them being obtained with determinations at intervals exceeding 0.33s.

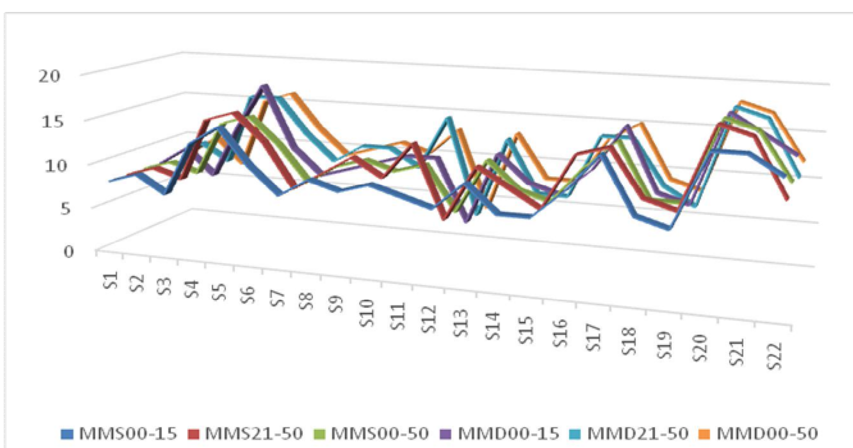

Fig. 1. Variation in median values for average travel speed of the left hand and right hand in the IA (22 subjects, three time intervals analyzed: 0-15s, 21-50s, 0-50s)

Although there is a variation in the results, depending on the time when the determination was performed, the number of sleep cycles in the previous night and the degree of physical and mental fatigue subjectively felt, it has been noted a clear variation in the coefficient of variation of average speed, in the mode (as an indicator of the data homogeneity and representativeness of average values and, secondarily, of the precision in coordination) (Table 3). Average speed values, in the mode, were closer to the target of 10 mm/s compared with the results achieved by the IG (I0-15: 10.39±1.51mm/s; I21-50: 11.26±2.70mm/s; I0-50: 10.92±2.06mm/s).

Table 3. Statistical indicators for the secondary assessment (SA2)

	Left hand				Right hand			
	Mean value		Std. Dev.		Mean value		Std. Dev.	
	general	dt<0.33s	general	dt<0.33s	general	dt<0.33s	general	dt<0.33s
Coef. Var. 0-15	0.373	0.312*	0.085	0.051	0.372	0.286*	0.109	0.083
Coef. Var. 21-50	0.371	0.303*	0.086	0.052	0.465	0.348*	0.221	0.090
Coef. Var. 0-50	0.375	0.311*	0.082	0.052	0.455	0.343*	0.199	0.092
Quartile** 0-15	5.34	4.06	1.80	1.06	5.28	4.06	1.65	1.06
Quartile 21-50	5.71	4.75	1.97	2.17	6.00	5.31	2.09	2.24
Quartile 0-50	5.56	4.43	1.88	1.75	5.53	4.43	1.64	1.45

* Highly statistically significant lower values (p<0.01%)

** Secondary indicator of variation in average travel speed (when the coefficient of variation is higher than 35%)

Discussions

The conclusion drawn after the first two assessments (IA, SA1), also supported by the results in the third assessment (SA2), has been that there is a real difficulty in performing ultra slow motions at a constant speed and that an assessment conducted at increasingly shorter intervals may highlight a progressively higher variation in average travel speed, in the mode.

Similar assessments performed through serial testing at average intervals of 0.11s, 0.33s, 0.50s, 1.50s have confirmed results for lower coefficients of variation (towards 35% and below 35%) with increasing the testing interval, therefore a higher homogeneity for the variation in speed, namely a "more constant" speed.

The consequence of specific training based on ultra slow motions, although indicating an improvement in the precision of coordination (for both the computerized testing and training testing to assess the accuracy of forehand), emphasizes functional limitation and the real incapacity to perform a coherent, continuous, smooth motion at these slow speeds.

Other researches regarding the efficiency of super slow training can be found in the studies like Wintt's (2001), who demonstrates that this type of exercising can lead to positive effects on strenght development by improving the neuromuscular control.

Two imperatives for further research can be revealed from the results of this preliminary study: detailed studies to track the efficiency, and therefore the appropriateness of using training based on ultra slow exercises (USMIT) in performance sports preparation, especially for sports games, and mass assessment studies for this coordination ability, namely precision at ultra slow speeds.

Conclusions

The data analyzed for the three case studies (IG, SG1, SG2) reveal an increased variation in average speed per testing time unit, as the time unit is increasingly shorter. Understanding these data in the somatic and functional context of muscle contraction triggering, we can say that the attempt to perform an ultra slow motion (0.5-20mm/s) at a constant speed is rather a sequence of fine accelerations and decelerations, which are indirectly captured through the higher variations in speed at shorter measurement intervals.

In other words, speed appears more as a by-product achieved by the fine coordination in the composition of forces of the agonist and antagonist muscle groups, and it can be thus framed rather as an intermediate component of motor ability.

Analyzing and using a standardized classification for the diverse types of slow physical exercises can be beneficial for research, but also for the users of these types of exercises, in order to reduce confusion in the various uses of the terms: slow, very slow, super slow, and to implement a motion close to the limit of human physiological capability: ultra slow exercise.

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For all of our participants from my study I want to say thank you.

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