Russian Journal of Biomechanics, Vol. 3, № 4: **-**, 1999

KINEMATIC ANALYSIS OF AUTOMATIC STEPPING OF UNLOADED LEGS ELICITED BY DIFFERENT MEANS IN HUMAN

V.A. Selionov, O.B. Kazennikov, Ju.S. Levik, V.S. Gurfinkel

Laboratory of Neurobiology of Motor Control, Institute for Information Transmission Problems, Russian Academy of Sciences, Bolshoy Karetny, 19, 101447, Moscow, Russia

Abstract: Kinematic and electrophysiological characteristics of stepping movements of unloaded legs suspended in horizontal plane were investigated. Movements were either voluntary initiated or evoked by different central and peripheral influences, activating automatic locomotory mechanisms. Movements could be evoked: 1) by vibration of different muscles of the suspended legs, 2) by passive leg movement during execution of Jendrassik manoeuvre, 3) during muscle relaxation after isometric contraction of leg muscles (Kohnstamm phenomenon). The vibration elicited rhythmic movements in hip and knee joints of both legs, persisting till the end of vibration. Similar stepping movements were activated during execution of Jendrassik manoeuvre or after isometric contraction of leg muscles. During evoked stepping electromyographic patterns were similar to those during voluntary stepping under the same conditions. Kinematics of angular movements in hip and knee joints during automatic and voluntary air-stepping was also similar. It is supposed that the initiation of rhythmic movements is due to the activation of central mechanisms of pattern generation.

Key words: locomotion, vibration, Jendrassik manoeuvre, Kohnstamm phenomenon

Introduction

Systematic studies of locomotion began at the turn of the century as investigation of kinematics of human walking [1, 2]. Later on, some data were obtained on energy balance of human locomotion, dynamics of walking and running, and electrical activity of muscles during locomotion. Bernstein [3] was one of the first scientists who emphasized the regulatory aspects of the locomotion. He attempted to analyze them on the basis of studying various kinds of locomotion; its maturation in ontogeny, disintegration in pathology and aging; compensatory and adaptive changes in pathology and orthopedic clinics. For the last three decades, the interest has been focused on the study of neurophysiological mechanisms of generation of locomotor movements in various animal species (from lamprey to cat). Considerable progress has been obtained in these studies, initiated by the pioneering work of Shik *et al.* [4]. In particular, it was shown that the basic pattern of animal locomotion is determined by central pattern generator, i.e. by a set of neuronal mechanisms, capable to generate cyclic activity even in the absence of the supraspinal influences (after spinalization), peripheral feedback (after deafferentation), or real limb movements (fictitious locomotion after curarization). However, it is still difficult to make bridge between the animal studies of the central locomotor mechanisms and the investigation of human walking. The existence of the central locomotor generators in apes and humans was denied by some authors, because of deviant type of locomotion and advanced cephalization of motor function [5]. So, the debatable problem of such a generator in human spinal cord became a subject of intensive research. Recently, it was shown that rhythmic leg muscle activity and leg movements in patients with spinal cord injuries could be evoked by rhythmic epidural stimulation of the dorsal surface of the spinal cord [6] or by long-term treadmill training [7,8]

However, the studies on spinal patients cannot conclusively answer the question about the role of central generators in human locomotion. First of all, the state of the spinal cord chronically deprived of the descending influences is altered considerably, and the normal mechanisms of locomotion control might be also modified. On the other hand, there are doubts that rhythmic leg movements during epidural stimulation are generated by the same mechanisms as the normal locomotion. Weakness of the evoked activity, muscle atrophy, etc. make the comparison of the angular excursions in main joints and inter-joint and inter-limb coordination between the evoked movements and normal stepping difficult.

The arguments cited above suggest that the further progress in the study of the central stepping mechanisms in humans is highly restrained by the lack of the methods of involuntary activation of stepping movements in healthy man. If such methods were found, they could open the possibilities to compare the parameters of voluntary and automatic locomotion and study various central and afferent influences on the evoked locomotion. This could result in considerable progress in understanding the mechanisms of human locomotion and answer many unsolved questions.

What methods of activation of involuntary locomotion in man could be proposed? Animal experiments show that locomotor automatism can be activated by electrical stimulation of the bulbar or spinal locomotor regions, by chemical stimulation of some brain structures or by appropriate afferent stimulation. Only non-invasive methods can be used in healthy persons, so the electrical stimulation of the spinal cord and the application of chemical substances should certainly be excluded. Thus, only use of some type of afferent stimulation can be considered. Vibratory stimulation seemed to be the most appropriate way of increasing afferent influx because it selectively activates spindle receptors. Vibration evokes not only local responses in stimulated muscle (tonic vibration reflex, TVR [9]) or in its antagonist (AVR) [10], but also responses in distant muscles [11]. The effects on remote muscles and sustained long-term changes in state of motor system after vibration suggest that the vibration enhances the level of tonic readiness in spinal and supraspinal structures. The role of tonic readiness was demonstrated in 1915 by Beritov [12], who believed that a high tone level is one of the most important conditions for generation of rhythmic movements in response to afferent stimulation in chronic decerebrate cat. Lately, the role of the appropriate tone level for evoking locomotion was shown in the studies with electrical stimulation of cat brainstem [13]. Therefore, an increase in spinal excitability due to the afferent influx evoked by vibration might activate the stepping generator giving rise to the triggering of rhythmic movements. [14,15]. The Jendrassik manoeuvre - the unspecific increase of muscle’s tone during strong voluntary contraction of hand muscles [16,17,18] - also could be used to influence the excitability of nervous system. Changes of muscle tone also occurred during Kohnstamm phenomenon: a non-voluntary muscle activation after their longlasting (30-60 sec) isometric contraction [19,20]. Since the muscle forces due to effects of vibration, Jendrassik manoeuvre or Kohnstamm phenomenon are too small for overcoming the weight, it is necessary to exclude influence of gravity by leg unloading for manifestation of locomotor automatism. The present work was focused on investigation of the kinematic characteristics of stepping movements, both evoked in healthy humans by various central and peripheral influences and performed by them voluntarily under the same conditions.

Materials and methods

Experiments were carried out using suspension of the legs that enabled the subjects to make stepping movements in a horizontal plane without restriction of mobility in joints of both legs (Fig. 1). The suspension allowed to eliminate the influence of the force of gravity on the evoked movements and to investigate legs movements at minimal muscle activity. The subjects lay on a side in a convenient pose in such a manner that both legs were suspended in

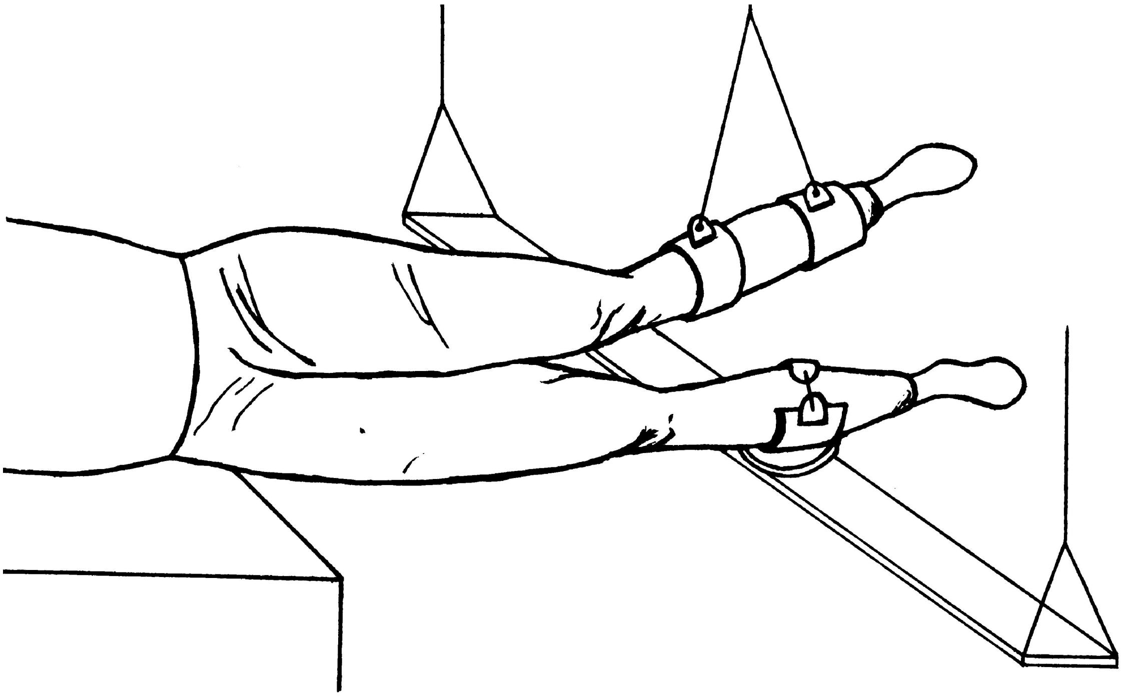

Fig.1. The scheme of arrangement for a horizontal suspension of lower extremities.

a horizontal plane. Such position did not limit natural movements of legs. Suspended relaxed legs in an equilibrium state assumed the configuration determined by relative elasticity of agonists and antagonists. Equitonometric angles at the different subjects were in the range 137-158? in hip joint and 115-156? in knee. The resistance to leg movement was so small that the legs passively shifted from the equilibrium position returned back within range of 3-5? from initial position. After the deviation from neutral position legs could make only half or one complete cycle of oscillation because of viscosity of muscles. The subjects were asked to relax completely and do not interfere with anticipated movements. The movements in joints were recorded by goniometers, attached over axes of rotation of hip and knee joints. The vibrator was attached above a belly or a tendon of a muscle by rubber band. The amplitude of vibration was about 1 mm, frequency of vibration was varied from 20 up to 60 Hz (various for the different subjects). EMGs of thigh and shank muscles were recorded by surface electrodes.

For activation of cyclic movements during Jendrassik manoeuvre experimenter took the relaxed leg of the subject and made by it 1-2 cycles simulating the stepping movements in hip and knee joints. Leg movements after one - two passive cycles of one leg applied by experimenter were compared in trials with and without Jendrassik manoeuvre to evaluate its effect. The subject maintained muscle contraction with various efforts during 10-20 seconds. Duration of performance of Jendrassik manoeuvre and level of effort was monitored by electrical activity of the flexor of the elbow joint (Brachioradialis m.). In a part of experiments vibrators were attached to leg muscles or to their tendons. Leg suspension could change the kinematics of stepping movements. To assess the characteristics of the air-stepping movement in suspension set-up subjects were asked to simulate volitionally movement forward and backward. The characteristics of evoked movements were compared to those of voluntary movements under the same conditions.

Cyclic movements were explored also during Kohnstamm phenomenon [11,12]: development of involuntary tonic activity accompanied with facilitation of some motor reactions after strong isometric muscle contraction lasting 40-60 seconds. On a command of

Table 1. Main parameters of elicited stepping.

	Vibration			Jendrassik manoeuvre			Kohnstamm phenomenon		
Sub	T, s	A_h,°	A_k,°	T, s	A_h,°	A_k,°	T, s	A_h,°	A_k,°
1	1.85	43	90	1.82	33	78	1.75	37	93
2	1.83	18	70	0.98	13	96	0.93	53	106
3	1.20	40	126	1.75	38	89	1.67	43	94
4	1.77	19	86	1.55	16	84	0.82	36	88
5	1.66	11	34	1.43	10	53	-	-	-
6	1.94	15	40	2.19	18	58	2.4	7	28
7	2.05	30	40	2.27	13	23	1.82	31	77
8	1.75	29	81	1.62	24	48	1.59	26	65
9	1.72	9	20	1.7	29	53	1.82	19	31
10	-	-	-	1.88	7	10	2.4	25	52
11	1.9	27	54	1.85	58	33	1.73	30	45
12	-	-	-	1.93	22	35	2.06	21	48
Mean.	1.76	24.10	64.10	1.75	23.42	55.00	1.73	29.82	66.09
SD	0.23	11.66	32.35	0.34	14.41	27.31	0.50	12.47	27.11

Parameters of stepping movements, evoked by vibration, during Jendrassik manoeuvre and after voluntary isometric contraction of muscles (Kohnstamm phenomenon) are represented for all subjects (Sub): T – period of stepping movements in seconds, A_h – amplitude of movement in hip joint in degrees, A_k – amplitude of movements in knee joint in degrees. In lower rows mean values (Mean) and their standard deviations (SD) for all subjects are presented.

the experimenter the subjects during 30-45 seconds tried to flex or extend one or both legs against different resistances. Immediately after the relaxation legs were released and the arising movements were recorded.

Results

Vibration of legs muscles. Ten of 18 subjects were sensitive to vibration. Continuous vibrating stimulation of one of muscles of hip, shank or feet sufficed for eliciting of locomotor-like movements. The latent periods of a beginning of movement strongly varied from several seconds up to several tens of seconds irrespective of which muscle was exposed to vibration. Extension in joints of one leg was always accompanied by flexion in the same joints of other leg. Thus, the movement of end point of both legs occurred in counter phase. Length of a "fictitious" step (distance between extreme points) was about 0.6-1.5 meters. The movements proceeded during all time of vibration application (up to 5 minutes). After cessation of muscle vibration a leg could make from 1 to 5 cycles before complete halt. The simultaneous vibration of two agonists of one leg, as well as vibration of two muscles of both legs was usually more effective, than vibration of one muscle. In some subjects in the first experiments only the simultaneous vibration of two muscles caused stepping. After one - two experiments on the same subject the efficiency of vibration increased and vibration of a single muscle became sufficient for eliciting of rhythmic movements. The simultaneous application of vibration to flexor and extensor did not suppress eliciting of rhythmic movements and even was more effective. In this case evoked stepping occurred with smoother transition from flexion to extension. It was possible to induce stepping by vibration of muscles, which were not involved in rhythmic activity (for example, flexor digitorum brevis m.). During evoked stepping the angular excursions in leg joints were characterized by large amplitude: approximately 50-70? for a hip joint and 60-100? for a knee joint. The period of movements was in the range 1.6-3.5 s (mean ± SD equals 1.76±0.23) and did not depend on vibrated

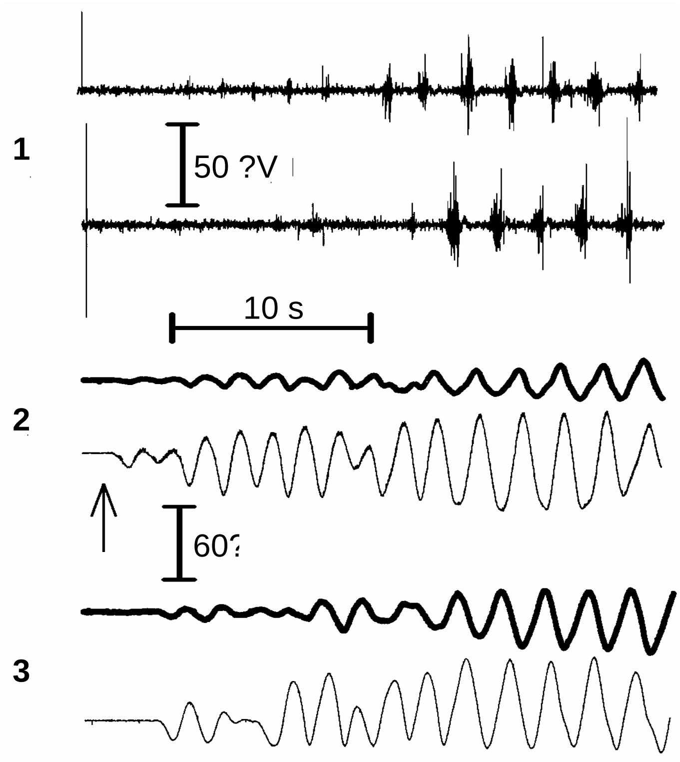

Fig.2. Stepping movements evoked by vibration, applied to leg muscles. 1 – EMG of extensors of right (top EMG) and left (bottom EMG) hip, 2 - change of angles in hip (thick line) and knee (thin line) joints of the right leg, 3 – the same for the left leg. The arrow specifies the start of the application of vibration.

muscle. During one trial the duration of a cycle was rather stable (SD in a range 0.1-0.2 s) (Table 1, Fig. 2). Kinematics of the evoked movements did not depend on an anatomic arrangement and function of vibrated muscle (proximal or distal, flexor or extensor, etc.). Nevertheless, if the vibration was put to a muscle involved in evoked stepping, the leg movements could have sharper transition from flexion to extension. The movements caused by vibration of muscles, not participating in evoked stepping, were perceived by the subject as smoother and close to natural. The influences of frequency of vibration on stepping period were weak and unsystematic. The simultaneous vibration of two muscles caused movements approximately with the same duration of a cycle, as vibration of one muscle.

Phase shift between changes of an angle in hip and knee joints was used as one of parameters for comparison with voluntary movements. Phase shift was measured in fractions of a cycle. For this purpose a time interval between the maximal values of hip and knee angles was divided by the period of rhythmic movement. The phase shifts were in the range of -0.5 up to 0.5, i.e. if the shift exceeded 0.5, the unity was subtracted from this value. Thus, the negative value of a phase shift meant a lead, and positive – a lag of changes of a knee angle relative to changes in hip angle. The movements in a knee joint could outstrip movements in hip joint (mean ± SD –0.19±0.09), that resulted in extension of hip with extended shank. In this case the subjects described movements as forward stepping. The phase shift during forward stepping could be due to the inertia of shank. The movements in the same joints of different legs occurred almost in counter phase (difference from exact counter phase was less than 0.05 cycles).

In other type of evoked stepping the changes in a knee joint lagged a phase changes in hip joint by 0.21±0.12 s. Thus, the extension of hip occurred with the flexed knee. The flexion of hip outstriped flexion of shank and occurred at the extended knee. In this case movements

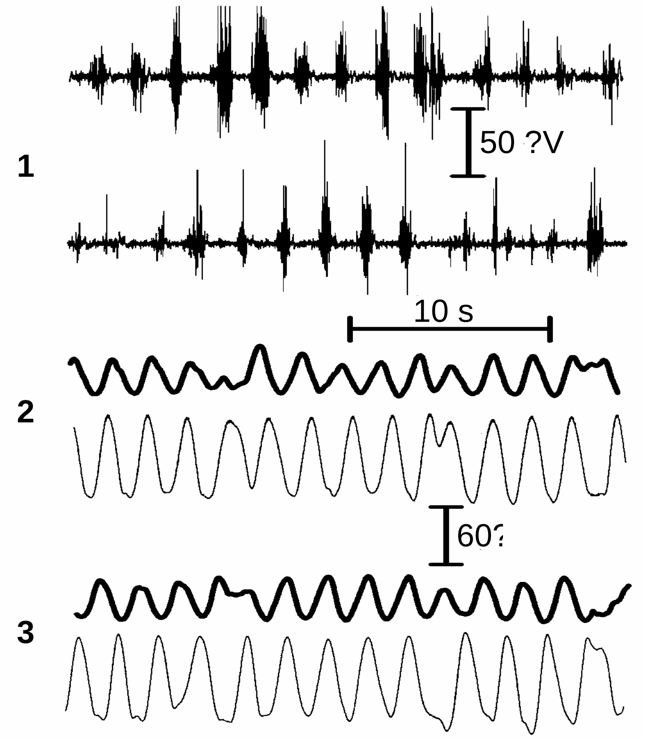

Fig. 3. Voluntary stepping movements of legs. Designations as in Fig. 2.

were subjectively perceived as backward locomotion. This delay of movement of a knee joint in relation to hip joint could not be a consequence of inertia of a shank. During leg movements with positive phase shift the amplitude of hip movements was somewhat greater, than during movements with negative phase shift (63°±23° and 49°±19°, correspondingly), and movements in knee joints were almost identical (79°±36° and 79°±21°, correspondingly).

Voluntary air-stepping. During simulation of stepping movements the changes of angles in hip and knee joints were smooth (almost sine wave) (Fig. 3). The amplitudes of changes of angles in hip and knee joints were approximately two times greater than corresponding values during normal ground locomotion, i.e. coincided with amplitudes during evoked stepping (Table 2). During voluntary forward locomotion flexion of a knee outstriped flexion of hip, and during imitation of backward stepping lagged behind (phase shifts – 0.19±0.06 and 0.18±0.15, correspondingly). During forward stepping extension of hip occurred at extended knee. In case of backward stepping extension of hip occurred at the flexed knee, and flexion at extended. Both forward and backward voluntary air-stepping was similar to corresponding evoked movements by their phase relations.

Jendrassik manoeuvre. The preliminary testing of influence of Jendrassik manoeuvre on evoked movements was carried out on 16 subjects. In 12 of them the weakly damped cyclic movements were observed during all period of performance of Jendrassik manoeuvre.

In response to 1-2 passive steps of the upper or lower leg applied by the experimenter under a resting condition, the leg movements continued only for 1-2 cycles. Another leg was not involved in movements (Fig. 4). However, if one or two passive stepping cycles of single leg were carried out during Jendrassik manoeuvre, not only manipulated leg continued self-sustained cyclic movements, but the second leg was also involved in the movement with a delay of one - two cycles. The movements of both legs from the very beginning became alternative. In antagonistic muscles of both legs during Jendrassik maneouvre (more often in muscles of the leg passively moved by the experimenter) it was possible to see EMG bursts in the second part of a passive cycle. During passive movements without Jendrassik manoeuvre

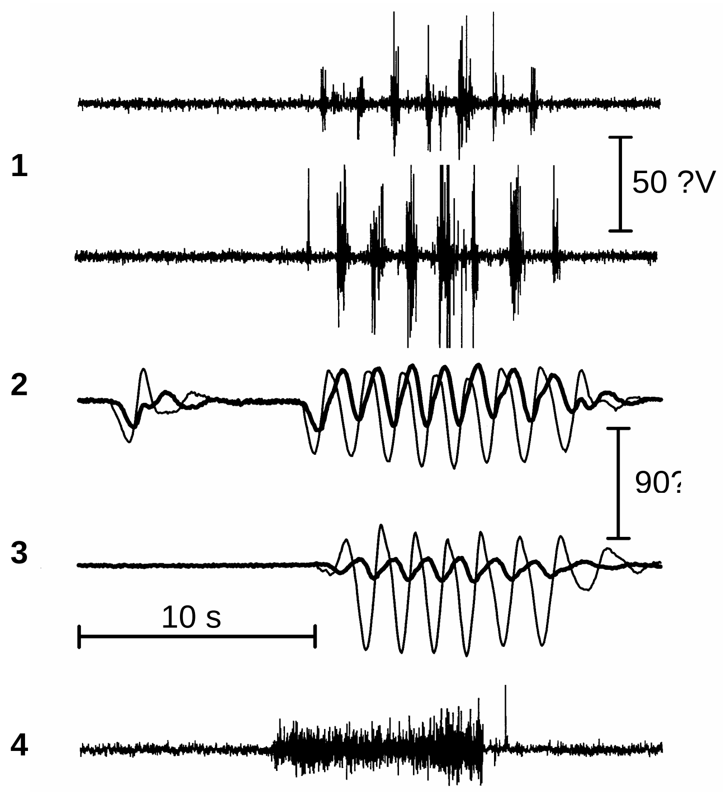

Fig. 4. Stepping movements activated by passive movement of a leg during performance of Jendrassik manoeuvre. 1-3 – the same as in Fig. 2; 4 – EMG of extensor of an elbow indicates the time of performance of Jendrassik manoeuvre.

Table 2. Main parameters of voluntary stepping.

	Voluntary stepping		
Sub	T, s	A_h,°	A_k,°
1	1.85	40	90
2	1.05	36	66
3	1.42	62	95
4	1.81	16	84
5	1.31	44	62
6	2.14	55	103
7	1.73	29	68
8	1.95	39	46
9	1.35	60	81
10	1.73	17	70
11	1.98	23	49
12	1.8	29	67
Mean	1.68	37.52	73.42
SD	0.32	15.63	17.58

Parameters of voluntary stepping are represented for all subjects. The designations as in table 1.

such bursts were either totally absent, or have very small amplitude. During cyclic movements reciprocal activity was observed in antagonists of one joint. Same reciprocal activity was observed in the homonimous muscles of different legs.

Such picture took place in 10 subjects. In 8 subjects the cyclic movements persisted up to the end of Jendrassik manoeuvre. In one subject the movements continued up to the end of Jendrassik manoeuvre, if this manoeuvre was accompanied by subthreshold vibration of leg muscles. In one subject the movements disappeared, despite of a combination of Jendrassik manoeuvre and vibration. In all cases the second leg was involved in movements. During performance of Jendrassik manoeuvre an additional activity in legs' muscles was not observed before appearance of cyclic movements: there were no changes in the values of inter-link angles and in the level of electrical activity of recorded muscles (Fig. 4). The evoked movements of both legs proceeded in counter phase: flexion in hip joint of one leg occurred simultaneously with extension in hip joint of another. The same pattern was observed in knee joints too. Thus, the phase relations in hip joints were established immediately after a beginning of movements. For each leg the movements in a knee joint occurred with phase shift in relation to a hip joint. The value of phase shift was typical for evoked and voluntary "air-stepping", performed by one leg and was equal to -0.22±0.07 s in forward stepping and 0.16±0.06 s in backward stepping.

The direction of movement could change spontaneously during the same test. Thus we have not found out law of switching of a direction of movement. The experimenter could apply passive movements, simulating forward or backward stepping. The direction of initiated stepping movements during Jendrassik manoeuvre could correspond to movements applied by experimenter or spontaneously change to the opposite. The rhythmic movements of both legs could be initiated by passive movement in single joint (knee or hip). With increase of effort developed by the subject during Jendrassik manoeuvre, the attenuation of movements decreased (if it took place initially), the movements became more intensive: their frequency and amplitude increased. The period of stepping movements was in the range 0.98-2.27 s (on the average 1.75±0.34 s). The rhythmic movements during performance of Jendrassik manoeuvre could be initiated by the application of short-lasting vibratory stimulation to muscles of one or both legs even without a passive cycle.

The interaction of Jendrassik manoeuvre and applied vibration was investigated in experiments with a small level of a voluntary contraction of muscles involved in Jendrassik manoeuvre. During performance of Jendrassik manoeuvre with small effort the movements quickly disappeared. However, vibration of leg muscles applied on the background of Jendrassik manoeuvre reduced attenuation or resulted to stable stepping movements and prolonged effect. At the same time Jendrassik manoeuvre influenced ongoing locomotion, caused by vibration: it resulted in increase of amplitude and frequency of stepping movements.

In some subjects Jendrassik manoeuvre could elicit generation of stepping without additional facilitatory factors. The EMG-pattern in this case did not differ from one typical for other kinds of voluntary or evoked air-stepping.

Kohnstamm phenomenon. The cyclic movements also arose after sustained isometric contraction of legs' muscles (Kohnstamm phenomenon). Stepping movements were clearly expressed after a contraction of various muscles of legs during 30-45 s with their subsequent relaxation. Under these conditions "air-stepping" proceeded for 5-60 s in 11 subjects (from 19 investigated). Both rate and duration of the initiated movements depended on number of muscles involved in a conditioning contraction, on their functional role (flexors or extensors, homonimous or heteronimous). After a simultaneous isometric contraction of antagonist muscles of different legs stepping movements were more prolonged, than after a contraction of agonist muscles. Only in one subject the contraction of agonist muscles resulted to simultaneous synchronous movements of both legs with transition to usual counter phase pattern after some cycles. After the contraction of muscles of single leg the movements were weak or did not arise at all.

The elicited movements were characterized by a typical pattern of counter phase movements in the homonimous joints with alternation of activity in flexor and extensor muscles (Fig. 5). The phase ratio of movements in hip and knee joint always corresponded to

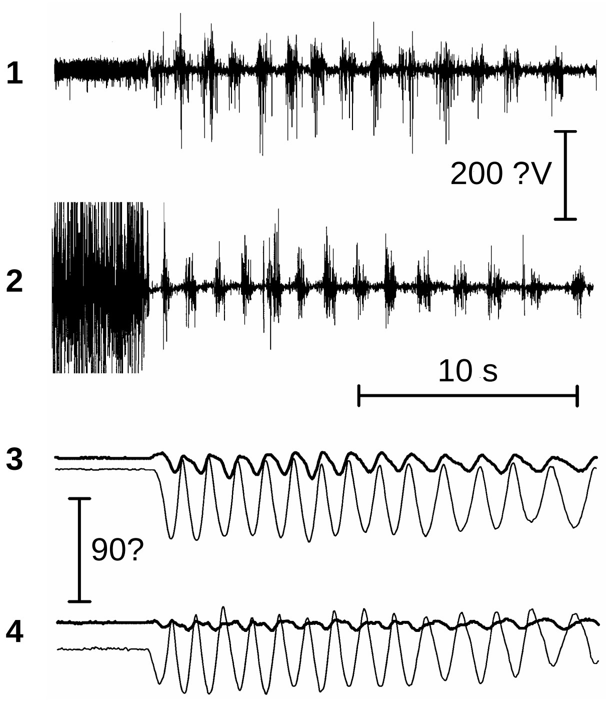

Fig. 5. Stepping movements after a voluntary contraction of extensor of right leg and flexor of the left leg. Designations as in Fig. 2.

forward stepping. In all cases movements at first increased, and then their frequency and amplitude declined; the maximal rate of stepping was observed after some (2-3) cycles after release of the legs. The minimal periods of cyclic movements during Kohnstamm phenomenon were shorter, than the periods of movements initiated by vibration or Jendrassik manoeuvre and were equal to 1.73±0.50 s (Table 1). The cyclic movements after isometric contraction were observed even in those subjects, who did not react to the application of vibration (3 subjects).

In some subjects it was possible to evoke additional stepping movement on a background of the completely damped movements by a single passive swinging of one leg, application of subthreshold vibration or by performance of Jendrassik manoeuvre. However these influences did not evoke leg movements if they were applied with the same parameters without a preliminary conditioning contraction of muscles of the suspended legs.

Discussion

Our experiments demonstrated that in the healthy human it is possible to evoke automatic cyclic leg movements by the application of vibration to leg muscles, by performance of Jendrassik manoeuvre, and by use of Kohnstamm phenomenon producing the postactivatory facilitation. Certainly, observed "air-stepping" substantially differs from real walking by absence of feet-support interaction, elimination of the gravitational moments by suspension and lack of the task of body weight maintenance and preservation of balance. Therefore, it is certainly impossible to put a mark of equality between the air-stepping and real locomotion. It is possible to conclude that the movements of legs observed in our experiments are generated by the same mechanisms, which in usual conditions are responsible for normal walking. What reasons permit to consider rhythmic movements, observed in our experiments, as analog of locomotion? The characteristics of the evoked movements corresponded to parameters of voluntary air-stepping. Apparently, it is possible to assume, that the generation of cyclic movements in our experiments is due to the activation of the same stepping automatism that is responsible for normal stepping. One of arguments for such assumption is that the evoked movements did not differ from voluntary stepping movements which are carried out by the subjects in the same conditions of a horizontal suspension. The movements in hip and knee joints occurring with appropriate phase shifts, require the coordinated activation of muscles of different joints. So, they can not be caused simply by work of two-joint muscles, demanding the involvement of inter-joint and inter-limb synergies.

It worth noting, that the execution of Jendrassik manoeuvre changes the level of tonic readiness, apparently, by means of central descending influences. The effect of continuous muscle vibration is connected with enhanced afferent inflow, and postactivatory facilitation could have both central and peripheral origin. However, despite of differences in the nature of influences initiating stepping movements, these movements appear identical. It allows us to assume that all kinds of influences activate the same automatisms. Activation of non-voluntary stepping movements under the conditions of partial or complete unloading can be useful as an experimental approach to the study of basic mechanisms of activation of locomotor rhythmicity. It could also have a perspectives of possible application in clinical practice.

The study was supported by RFFI grants № 97-02-17526 and № 99-04-48015.

References

1. MAREY E. **Mekhanika zhivotnogo organizma. Peredvizhenie po zemle i vozdukhu (Mechanics of the Animal Organizm: Locomotion on the Ground and in the Air).** St. Petersburg. Znanie, 1875 (in Russian).
2. MUYBRIDGE E. **The human Figure in Motion**. London, Chapman and Hall, 1901.
3. BERNSTEIN N .A. **On the Construction of Movements**. Moscow, Medgiz, 1947 (in Russian).
4. SHIK M.L., SEVERIN F.V., ORLOVSKY G.N. Control of walking and running by means of electrical stimulation of the mid-brain. **Biophysics**, 11: 756-765, 1966 (in Russian).
5. VILENSKY J.A., MOORE A.M., EIDELBERG E. and WALDEN J.G. Recovery of locomotion in monkeys with spinal cord lesions. **J Mot Behav,** 24: 288-298, 1992.
6. CALANCIE B., NEEDHAM-SHROPSHIRE B., JACOB P., WILLER K., ZYCH G. and GREEN, B.A. Involuntary stepping after chronic spinal cord injury. Evidence for a central rhythm generator for locomotion in man. **Brain,** 117: 1143-1159, 1994.
7. DIETZ V., COLOMBO G. and JENSEN L. Locomotor activity in spinal man. **Lancet**, 344: 1260-1263, 1994.
8. WERNIG A. and MULLER S. Laufband locomotion with body weight support improved walking in persons with severe spinal cord injuries. **Paraplegia**, 30: 229-238, 1992.
9. EKLUND G. and HAGBARTH. K.-E. Normal Variability of Tonic Vibration Reflexes in Man. **Exptl Neurol**, 16: 80-92, 1966.
10. ROLL J.P., GILHODES J.C., TARDY-GERVET M.F. Effect perceptifs et moteurs des vibrations musculaires antagonistes. **Arch Ital Biol,** 118: 51-71, 1980 (in French).
11. GURFINKEL V.S., LEBEDEV M.A., LEVIK Yu.S. Switching Effects in the System of Equilibrium Control in Man. **Neurofiziologia (Kiev),** 24(4): 297-304, 1992 (in Russian).
12. BERITOV I.S. About the main elements of locomotory movements: static tone and rhythmic limb reflex and their interaction. 3d communication. **Trans Imperial Acad Sci**, 3: 1117-1139, 1915 (In Russian).
13. MORI S., KAWAHARA K., SAKAMOTO T., AOKI M. and TOMIYAMA T. Setting and resetting of level of postural muscle tone in decerebrate cat by stimulation of brain stem. **J Neurophysiol**, 48: 737-748, 1982.
14. GURFINKEL V.S., LEVIK Yu.S., KAZENNIKOV O.V., SELIONOV V.A. Locomotor-like movements evoked by leg muscle vibration in humans. **European J of Neuroscience**, 10: 1608-1612, 1998.
15. GURFINKEL V.S., LEVIK Yu.S., KAZENNIKOV O.V., SELIONOV V.A. Is there a locomotor generator in man? **Human Physiol**, 24(3), 294-301, 1998 (in Russian).
16. BUSSEL B., MORIN C., PIERROT-DESEILLIGNY E. Mechanism of monosynaptic reflex reinforcement during Jendrassik maneuvre in man. **J Neurosurg Psychiatry**, 41(1): 44-54, 1978.
17. HAGBART K.E., WALLIN G., BURKE D., LOFSTEDT L. Effects of the Jendrassik maneuvre on use spindle activity in man. **J Neurosurg Psychiatry**, 38(12): 1143-1153, 1975.

18. DELWAIDE P.J. TOULOUSE P. Jendrassik maneuvre vs controlled conditioning the exitability of soleus monosynaptic reflexes. **Arch Phys Med Rehabil**, 61(11): 505-510, 1980.
19. KOHNSTAMM O. Demonstration einer katatonieartigen Erscheinung beim Gesunden. (Katatonusversuch). **Neurol Zentral Bl**, 34: 290-291, 1915 (in German).
20. MATHIS J., GURFINKEL V.S. and STRUPPLER A. Facilitation of motor evoked potentials by postcontraction response (Kohnstamm phenomenon). **Electroenceph Clin Neurophysiol**, 101: 289-297, 1996.

КИНЕМАТИЧЕСКИЙ АНАЛИЗ АВТОМАТИЧЕСКОГО ШАГАНИЯ, АКТИВИРУЕМОГО РАЗЛИЧНЫМИ СПОСОБАМИ В УСЛОВИЯХ РАЗГРУЗКИ КОНЕЧНОСТЕЙ У ЧЕЛОВЕКА

В.А. Селионов, О.В. Казенников, Ю.С. Левик, В.С. Гурфинкель
(Москва, Россия)

В работе исследовались кинематические и электрофизиологические характеристики шагательных движений разгруженных ног в горизонтальной плоскости. Циклические движения вызывались вибрацией разных мышц вывешенных ног при выполнении испытуемыми приема Ендрассика (повышения тонуса мускулатуры ног при сцеплении рук и их последующем напряжении), а также изменением уровня мышечного тонуса при использовании феномена Конштамма (изометрического напряжения группы мышц синергистов ног в течение 30-45 секунд с последующим расслаблением).

Кинематику движений, вызванных различными способами в условиях разгрузки, сравнивали между собой и с характеристиками произвольных движений в тех же условиях. Исследование осуществляли в установке с системой вывески ног, позволяющей испытуемым совершать шагательные движения без ограничения подвижности в суставах. Электромиографические разряды флексорных и экстензорных мышц бедра и голени во время инициированного шагания “в воздухе” отводились поверхностными электродами. Углы в тазобедренном и коленном суставах измерялись при помощи гониометров, закрепленных на осях вращения.

При непрерывной вибрации мышц одной или обеих ног выраженные ритмические движения наблюдались у 8 испытуемых из 18. Вибрация вызывала циклические движения в тазобедренном и коленном суставах обеих ног, которые продолжались в течение всего периода вибрации. Длина шага “в воздухе” (движение переноса стопы в передне-заднем направлении) была в диапазоне 0.6-1.5 м. Фазовые сдвиги между движениями в бедренном и коленном суставах могли быть как положительными, так и отрицательными в зависимости от направления шагательных движений, совершаемых испытуемыми, и соответствовали ходьбе вперед или назад (-0.22±0.07 секунд и 0.16±0.06 секунд для ходьбы вперед и назад, соответственно). Прием Ендрассика мог вызывать локомоторные движения с такими же периодами циклических движений и соответствующими межсуставными фазовыми соотношениями, как и при приложении вибрации. Суперпозиция вибрации и приема Ендрассика приводила к увеличению темпа и амплитуды вызванных движений. Тоническая активация мозговых структур после произвольного напряжения мышц ноги (феномен Конштамма) вызывала у части испытуемых автоматические шагательные движения, которые продолжались в течение 20-40 секунд и постепенно затухали, при этом период цикла был короче, амплитуда шагательных движений больше.

Полученные данные показывают, что при отсутствии опоры и снятии гравитационных моментов характеристики “шагания в воздухе” отличаются от кинематики шагания по земле. При этом характеристики вызванного и произвольного шагания в условиях вывески конечностей не отличаются. Библ. 21.

Ключевые слова: локомоции, кинематический анализ, колебания, прием Ендрассика, феномен Конштамма.

Received 05 October 1999