Contribution of Various Sensory Inputs to Vertical Stance and Locomotion in Humans: Robust Assessment with Stabilography and Motion Videocapture

Alexander Meigal, Elena Kravtsova, Liudmila Gerasimova-Meigal, Kirill Prokhorov, Alexandra Peskova
Petrozavodsk State University
Petrozavodsk, Russia
meigal@petrsu.ru

Abstract—**The purpose of this study was to evaluate reliability of basic parameters obtained with conventional stabilographic tests, and step characteristics recorded with motion videocapture, for fast robust assessment of the contribution of the vestibular system, vision, and proprioception to vertical stance and walking in healthy subjects. The contribution was computed as "weight coefficients" of each of the sensory input to the net motor outcome (the body balance at easy vertical stance and locomotion) at the conditions with deprivation of either vision (Romberg's test) or proprioception ("foot reaction" test), or both vision and proprioception. We found, that during easy vertical stance tested with stabilography, only the path length of the center of pressure presented relevant data. It allowed to estimate the contribution of the proprioception as cal. 0,5, while vision and the vestibular system both contributed roughly with 0,25. During walking, the vestibular system's contribution was 0,7 - 1,0 of the net share, while that of vision was negligible. These data generally correspond with the results obtained with more precise "science-intensive" methods. As such, conventional stabilography at various sensor-deprivation conditions could have had potential to assess, predict and prevent motor disorders.**

I. INTRODUCTION

The ability to locomotion, body balance and space orientation of the body is of vital importance for either quadripedal animal species or humans (bipedal species). *Locomotion* holds for the ability to actively relocate the body on the distance larger than the body's size, what actually means changing one's position on the surface of the Earth. The *body balance* accounts for the ability to keep vertical position in the Earth's gravitational field either under easy stance (static balance) or during locomotion (dynamic balance) with help of postural reactions, thus preventing falls. Falls, which indicate that the balance was ineffective, happen either due perturbations (external forces), uneven or slippery ground, or are spontaneous. Under all of these circumstances, falls are potentially dangerous due to direct damage (injures) to the bodily systems and organs. In older people, falls risk is especially high, what is caused by disordered motor control, weaker musculature and other identifiable factors [1]. Under neurological pathologies, e.g. Parkinson's disease (PD) or dementia falls risk is even higher [2].

There are three major sensory systems which help operating human motion and posture during active locomotion and at easy standing: 1) the vestibular system, 2) proprioception, and 3) vision. Each of these sensory inputs provides distinct spatial reference to perform and control motion [3]: 1) the vestibular system provides the *gravitational reference* (the sense of balance and gravity vector, and spatial orientation) what is important to distinguish between motion of the body and environment, 2) proprioception (the somatosensory system) provides the *egocentric reference* (information on muscle tension, joint position and motion, or statokinesthesia), and 3) vision provides the *allocentric reference* (spatial cues, coordinates and distances for extra-personal objects and the own body, and the visual vertical). The CNS constantly integrates these three sensory inputs (references) into coherent multisensory, maximally plausible representation of the body in the environment.

Human balance and motion, either during easy stance or just walking, are performed under permanent presence of the Earth's gravity (1G) and, therefore, evolutionally are under strong control of gravity. In a way, all kinds of motion are anti-gravitatory. Of the three above mentioned sensory inputs (references), vision is accounted as the least dependent of gravity. This means that under gravity modifications in the direction of either hypo- (<1G)- or hypergravity (>1G), vision input stays unimpaired. Unlike vision, the vestibular and proprioceptory sensory inputs are profoundly modified under G modulation. At some pathologies, one or two of the sensory systems could be severely impaired, malfunctioning, or totally lost, e.g. at total blindness or bad vision, pathologies of the internal ear and cerebellum. Also, healthy subjects occasionally have to operate under such factors as darkness, bad visibility, "sea legs" during maritime travelling, on ground/floor with stressfull features of surface (elastic, viscous, soft, uneven), vibrating or revolving ground in industrial or natural environment. Ingestion of some chemical agents, e.g. alcohol, and nausea may also seriously impair the body balance. This means that the role of different sensory inputs can be specific under different environmental and internal (personal) circumstances.

Usually, humans rely on all three sensory inputs (spatial references) during standing or walking, and each of these inputs has its "weight" coefficient (contribution) in the net control of balance, and in sum these coefficients make 1,0 [4], though the proprioceptory input (egocentric spatial reference) is usually underestimated [3]. Additionally, varying environmental and internal factors may substantially re-arrange the weight coefficient of a particular sensory input, what is known as "re-weighting" [4], [5]. For example, in patients with Parkinson's disease (PD) and older people contribution of vision to body balance at vertical stance is larger than that of younger healthy controls [5]. Also, older people and patients with PD were slightly more reliant on proprioception than younger controls [5]. As for the vestibular apparatus, it is reportedly not damaged in patients with PD [6]. More specifically, older people need to "watch and see" the environment when walking or standing, while younger subjects are reliant on the vestibular apparatus and proprioception. In a way, older people become more cautious, "vision-dependent" when walking, running, and going up and down stairs [6]. In children, integration of vision and proprioception also takes place during their development [7].

Currently, several instrumented, "science-intensive" methods are used, which allow accurate evaluating of weights of the sensory inputs [3, 4, 5, 8, 9]. There is market pain for a time-saving (fast), not-so-precisious (robust), easy-to-do (comprehensible), though still relevant, evaluation procedure of sensory-motor integration in the man during ageing and at pathologies of the nervous system, e.g. PD or dementia. This would be helpful to control treatment and rehabilitation of neurological patients, and to predict and prevent falls and, hence, injures.

II. RELATED WORKS

Several approaches are used to evaluate integration of vision, proprioception and the vestibular system. The one is to compute parameters in a linear feedback control system model of the postural control system during stabilography [4], [5]. This method is very precise but time-consuming and somewhat complicated from instrumental, analytical and interpretation point of view.

Also, there is a method of evaluation of proprioception and vision contribution to the body balance based on the characteristics of single stance stability, i.e. during standing on one leg [8]. This method allows characterizing the body balance with so-called "autonomy" and "average postural instability" extracted from the number of touching a sensor bar to prevent falling, and the range of correctional movements, both with eyes open and closed [8]. This method proved strongly predictive for falls in aged people and traumas in sports, and, therefore, preventive.

Finally, relative contribution of vision vs. proprioception can be assessed with help of reaching movements of hands [9]. In this study, vision and proprioception were almost equal by their contribution to the control condition, but vision was shown to increase by its weight in the condition of force perturbation.

Thus, multisensor processing of different signals by the CNS is widely studied in order to quantitize interplay of the sensory inputs and to judge on leading reference for varied ages, pathologies and normal special conditions of the man.

The present study was aimed at testing a robust, simplified assessment procedure based on some basic stabilography metrics and motion videocapture under conventional sensory-motor tests. Additionally, such method would have been time-saving, with higher throughput, and relevant for primary examination under field and hospital condition by physicians and nurses.

III. METHODS AND SUBJECTS

We started with the formula of Feller et al. [6] assuming that the net sensory contribution to easy stance or motion is 1,0 ($W_{vest} + W_{vis} + W_{pro} = 1$), where W_{vest} stands for contribution of the vestibular system, W_{vis} - of vision, and W_{pro} - of the proprioception system.

Subjects

Two groups of subjects volunteered to the study. Eleven young subjects in good health (aged 20-22 years, both males and females) were enrolled to the "Stabilography" group, and another 14 subjects of the same age - to the "Walking test" group. We used the protocol, earlier approved by the local ethic committee (statement of approval №34, 22.04.2015).

Sensory conditions

To separate all three sensory inputs from each other and digitize their particular **W**, subjects passed through stabilography and the walking test under 4 distinct sensory conditions: 1) with eyes open (EO/S) or 2) closed on solid (S) ground (EC/S), and 3) with eyes open (EO/F) or 4) closed on soft (foam pad, F) ground (EC/F). The first two conditions actually represented classic Romberg's test - standing at ease with eyes open/closed, in European stance (with "heels together" and "toes apart" at 30°), the third condition was performed within the paradigm of "foot reaction test" (easy stance on solid surface with eyes open and then on soft foam pad, again with eyes open). The forth condition (EC/F) was realized when subjects stood on foam pad with eyes closed. As such, the most challenging condition was EC/F (with reliability only on the vestibular system), while the least stressful - EO/S, with all three sensory inputs and references under operation. In sum, these experimental conditions allowed modeling the desired sensory combinations (Table I).

TABLE I. STUDIED SENSORY CONDITIONS AND CORRESPONDING SENSORY CONTRIBUTION

Condition	$\mathbf{W}_{vest}$	$\mathbf{W}_{vis}$	$\mathbf{W}_{pro}$	Formula for net **W** *
EO/S	+	+	+	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro} = 1$
EC/S	+	0	+	$\mathbf{W}_{vest} + \mathbf{W}_{pro} = 1$
EO/F	+	+	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} = 1$
EC/F	+	0	0	$\mathbf{W}_{vest} = 1$

* [6]

Procedures and instruments

Stabilographic measures. For stabilography we used a PC-based commercially available device (ST150, MERA, Moscow, Russia), which allowed measuring 3 basic metrics - 1) path length (L, mm) of center of pressure (CoP), 2) velocity of the CoP travel (V, mm/s), and the least small square of the CoP travel (S, mm^2) which included 95% of its points. Of these metrics, only the path length was directly measured by the apparatus, while the CoP's velocity and square were calculated as derivatives of the path length.

During the stabilographic tests, silence was strictly kept in the laboratory room, speaking was not allowed. Cellular phones were switched off to prevent unreliable vigilance reactions and, hence, movements. At all stabilography episodes the subjects were barefoot. When eyes were open, subjects watched the PC screen 2,5 m in front (with a landscape), what helped keeping same posture during tests. General scenery of stabilography is presented on Fig. 1.

Fig.1. Photography of the stabilography apparatus with (left) and without foam pad (right).

Romberg's test. During EO/S condition, subjects stood at ease for 30 s on the force platform of ST150 with eyes open, then (during EC/S) - for further 30 s with eyes closed (without changing position). Therefore, with formula EO/S - EC/S, or (EO - EC) x S one can calculate the so-called "visual gain" [9].

"Foot reaction" test. First, subjects started with standing on the force platform for 30 s in the EO/S condition. After that they stepped back, and the force platform was covered with the foam pad (20 cm thick), of the same size with the platform, and subjects stood further 30 s on it again with eyes open (EO/F). The foam pad was supplied with the arrows showing the position of feet which corresponded with such arrows on the platform in order to maximally fit the position on the platform during both conditions. Correspondingly, the formula EO/S - EO/F, or (S - F) x EO allowed evaluating the "proprioception gain" from feet.

For EC/F condition, subjects stood 30 s on the foam pad placed over the force platform, with eyes closed. This condition was the most challenging in respect with sensory control of stance, as subject had to rely only on the vestibular system. An example of the stabilogram (path of the CoP) record at the studied sensory conditions is presented on Fig. 2.

The walking test. The same 4 sensory conditions (in respect with ground solid/foam and eyes open/closed) were applied to the walking test. The foam pad brand was the same with those used in the stabilography test (3 x 4 m, 20 cm thick).

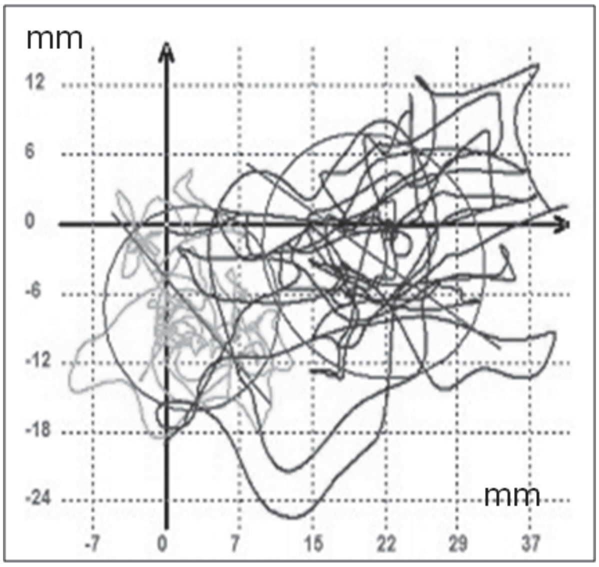

Fig. 2. Stabilogram at EO/S (loops inside of left circle) and EO/F (loops inside of right circle, dark gray) conditions. Circles present the least square including 95% of points of the CoP path. Note large loops representing body sway and reaction on it for the EO/F condition.

During the walking test subjects were instructed to walk straight (in the direction of camera) at comfortable pace, what usually constituted 6 steps (3 by each leg), within 10 s. The subjects performed this test barefoot under all sensory conditions. Before the test, light-returning spheres were attached with self-sticking material to knees and ankles of subjects for motion capture by a video analyzing system bilaterally (Videoanaliz 3D, Biosoft Ltd, Moscow, Russia). General schema and scenery of the walking test are presented on Figures 3 and 4.

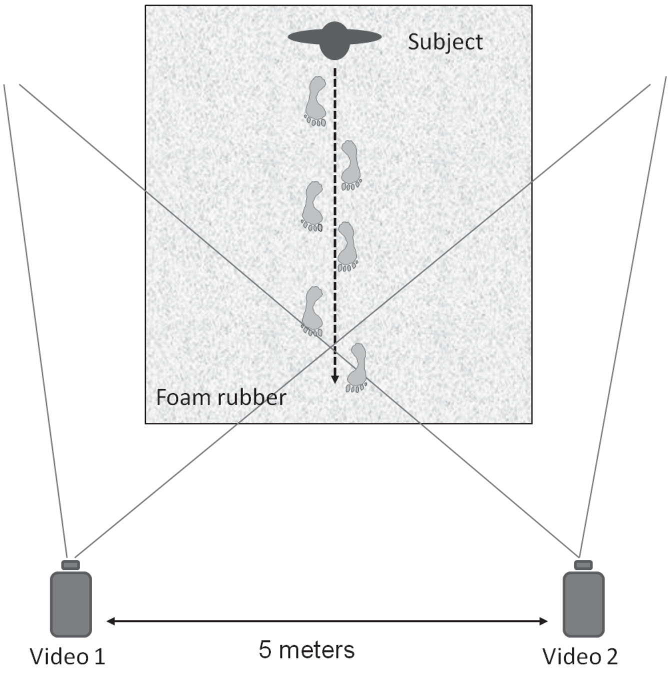

Fig. 3. General scheme of the motion video capture during the walking test.

The vector of walking (divergence from the straightforward direction) was not assessed in this study.

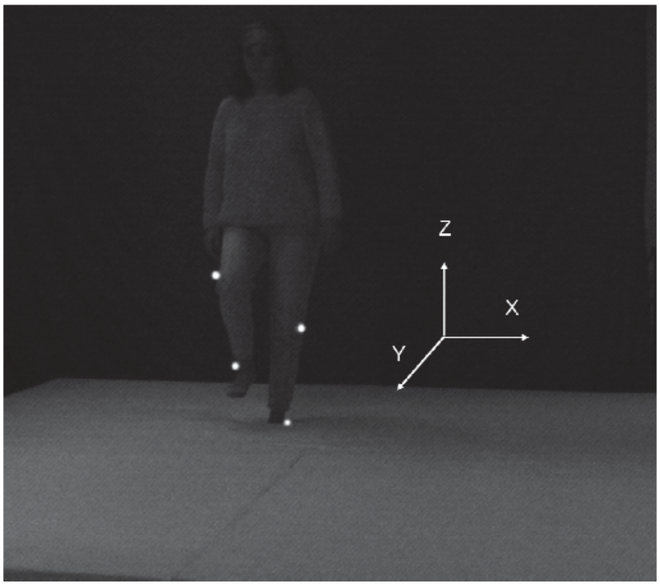

Fig. 4. Scenery of the walking test. Light returning spheres are attached to knees and ankles, bilaterally. The subject walks on the foam pad with eyes open (EO/F condition).

For metrics, we used the length of steps (mm), extracted from the 3D trajectories of light-returning spheres on the ankles, in the Y-axis, and the maximal height of knee rise during stepping (mm), bilaterally, in the Z-axis. Trajectory of the light-returning sphere of the right knee from Fig. 3 during three successive steps is presented on Fig. 5.

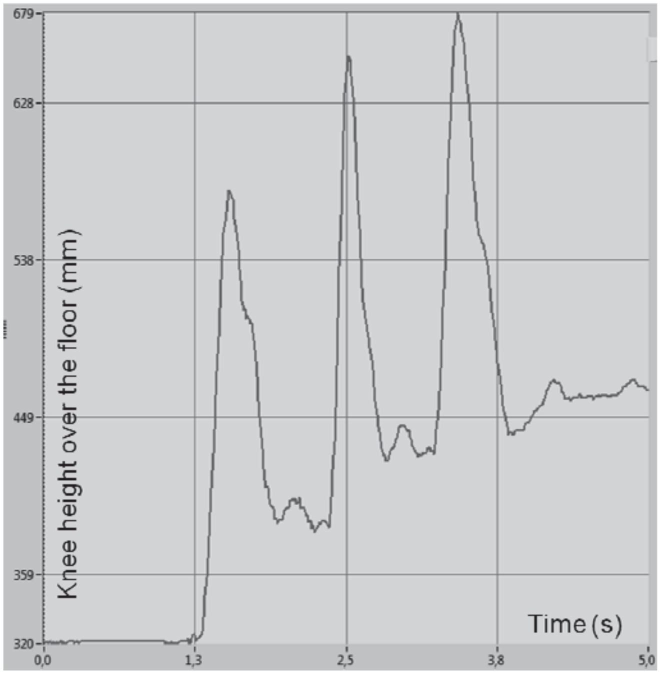

Fig. 5. Trajectory of the right knee with its height over the surface (floor) during 3 successive steps in the X axis. Note that after the first step the height of knee has increased by some 7 cm what was associated with stepping on the foam pad from the normal floor.

*Calculation algorithm of contribution of particular sensory input to the net sensory input (**W**)*

1. Under the EO/S condition, all three sensory inputs presumably contributed to **W**. For example, in subject X during stabilography, length path was 262,8 mm, and it was longer at other conditions (Fig. 6).

1	EO/S = **262,8** vest + vis + pro	EC/S = **326,5** vest + pro - vis	EO/F = **398** vest + vis - pro	EC/F = **849,1** vest – vis - pro
2	EC/F – EO/S = **586,3** vis + pro	**586,3 : 849,1 = 0,69** $\mathbf{W}_{vis} + \mathbf{W}_{pro}$		
3	$\mathbf{W}_{vest}$ = 1 – 0,690 = 0,310			
4	EC/S – EO/S = **63,7** vis	EO/F – EO/S = **135,2** pro		
5	**63,7 : 135,2 = 0,471 : 1** vis : pro	$\mathbf{W}_{vis}$ = 0,69 : 1,471 x 0,471 = 0,221		
	$\mathbf{W}_{pro}$ = 0,69 : 1,471 x 1 = 0,469	$\mathbf{W}_{vis} + \mathbf{W}_{pro}$ = 0,221 + 0,469 = 0,69		
6	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro}$ = 0,310 + 0,221 + 0,469 = 1,0			

Fig. 6. The algorithm of **W** calculation for the studied sensory inputs. Numbers at the left side correspond with those in the text. Bold numericals represent path length (mm).

2. At EC/F, L=849,1 mm, and that result corresponded with "pure" contribution of the vestibular system, as eyes were closed and ground was soft. Therefore, by subtracting of 262,8 from 849,1 we get joint contribution of vision and proprioception (586,3 mm).

With dividing 586,3 by 849,1 we get joint ratio of contribution of vision and proprioception to motion ($\mathbf{W}_{vis}$ and $\mathbf{W}_{pro}$), which in this case equals 0,690.

3. By subtraction of 0,690 from 1,0 we get particular share (contribution) of the vestibular system to motion ($\mathbf{W}_{vest}$ = 1 - 0,690 = 0,31).

4. Calculation of particular shares of vision ($\mathbf{W}_{vis}$) and proprioception ($\mathbf{W}_{pro}$). To proceed, we measured difference (growth) of the path length, correspondingly, after closing eyes (EC/S) and standing on foam (EO/F) in respect with the initial condition (EO/S). Subtraction of EO/S from EC/S supplied us with contribution of vision ("vision gain"), and subtraction of EO/S from EO/F - with that of proprioception ("proprioception gain"). For example, in subject X, EO/C was 326,5 mm. Correspondingly, "vision gain" was EC/S - EO/S = 63,7 (326,5 - 262,8). This means that eyes closing added 63,7 mm to the CoP path length. For "proprioception gain", EO/F - EO/S = 135,2 mm (398 - 262,8).

5. Thus, vision contribution corresponded to that of proprioception as 63,7 to 135,2, what makes $\mathbf{W}_{vis}$ / $\mathbf{W}_{pro}$ = 0,471. Then, we applied this proportion to net contribution of $\mathbf{W}_{vis}$ and $\mathbf{W}_{pro}$ (0,690) and got 0,221 for $\mathbf{W}_{vis}$ and 0,469 for $\mathbf{W}_{pro}$.

6. Sum of all sensory input contributions should equal 1,0. Indeed, $\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro}$ = 0,310 + 0,221 + 0,469 = 1.

Thus, in this particular subject proprioception contributed almost 50% to the net sensory control of body balance at vertical stance.

After that we calculated the re-weighted contribution under the condition of closed eyes (without vision) and the condition of soft ground (reduced proprioception). With closed eyes (deprivation of visual sensory input), the sensory contribution was distributed among the vestibular and proprioceptory systems (0,310:0,469 = 0,661; then 1:1,661x0,661 = 0,397 for the vestibular system and 1:1,661x1 = 0,603). In sum, 0,397 and 0,603 give 1,0. Similarly, at standing on the foam pad (deprivation of the proprioceptory input), the sensory contribution was distributed among the vestibular and vision (0,310:0,221 = 1,402; then 1:2,402x1,402 = 0,583 for the vestibular system and 1:2,402x1 = 0,417 for vision. In sum, 0,583 and 0,417 again give 1.

Calculation of the **W** during locomotion was done according to the same algorithm.

General approach to research modeling. Our approach to assess contribution of a particular sensory inflow was reduced to evaluation of the "impairment" to the function of the body balance exerted by its deprivation. As such, when a definite sensory flow is abandoned, the function (body balance) became "impaired'. Thus, the function of the body balance becomes less efficient, what has to be seen as L, S and S increase (increased travel of CoP). However, the function of the body balance in our study has never been totally destroyed, because all subjects were able to hold the vertical stance even with yeas closed and/or standing on a foam pad.

Statistical analysis. For statistics, we used the IBM SPSS 21.0 Statistics (IBM, USA). To detect influence of the sensory conditions on the studied stabilography and walking metrics we applied the Friedman's non-parametric test for multiply attempts (with Newman-Keuls correction).

IV. RESULTS

1. The "Stabilography" group. Mean values of the studied stabilometric parameters are presented on the Table II.

TABLE II. THE STABILOMETRIC PARAMETERS UNDER THE STUDIED SENSORY CONDITIONS

Condition	Path length (mm)	Velocity (mm/s)	Square (mm^2)
EO/S	219±66	7,3±2,2	185±171
EC/S	313±97	10,4±3,2	238±324
EO/F	382±99*	12,7±3,3*	255±229
EC/F	937±257**	31,2±8,6**	906±534*
p, Friedman	0,000	0,000	0,001

*<0,05, ** - p <0,01 in comparison with the original sensory condition (EO/S)

In general, all stabilographic parameters were smallest (best) in the EO/S condition, and worst - in the EC/F condition, what looks quite expected. For example, path length of CoP in EO/S condition was in average 220 mm, but its value was four times of that in EC/F condition. The velocity of CoP travel strictly corresponded with the CoP path length, while the square of CoP was also depended, though less, of them. The square of CoP was extremely variable among the subjects what is seen from its big standard deviation.

For example, in 4 subjects of 10, the square of CoP travel at closed eyes has decreased instead of being increased. The path length of CoP has, nonetheless, increased in all 10 subjects after closing eyes. Also, it looked so that closing eyes exerted a less pronounced effect of the studied parameters than standing on the foam (Table II).

The results on the contribution of particular sensory inputs to the net **W** are presented in Table III.

TABLE III. STUDIED SENSORY CONDITIONS AND CORRESPONDING SENSORY CONTRIBUTION

Condition	$\mathbf{W}_{vest}$	$\mathbf{W}_{vis}$	$\mathbf{W}_{pro}$	Formula for net **W**
EO/S	0,245±0,08	0,249±0,11	0,505±0,16 **	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro} = 1$
EC/S	0,342±0,15	0	0,658±0,15	$\mathbf{W}_{vest} + \mathbf{W}_{pro} = 1$
EO/F	0,503±0,11	0,497±0,11	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} = 1$
EC/F	1,0	0	0	$\mathbf{W}_{vest} = 1$
p, Friedman	0,000	0,000	0,001	p, Friedman

** - p <0,01 in comparison with the original sensory condition (EO/S)

The result indicates that the proprioceptory system (feeling of solid ground by the feet) was the most contributive to body balance during the vertical stance, as its share in the net sensory contribution was almost 0,5. Both vision and the vestibular system contributed by some 0,25. Correspondingly, younger healthy subjects are more reliant on proprioception, than vision, what is in line with precise measurements of sensory input contribution to vertical standing [5], [6].

It turned out that contribution of the studied sensory inputs to the CoP velocity was exactly the same with that for path length. Presumably, this followed from the fact that the velocity of CoP is a derivative from the path length. Therefore, we did not include these data to this paper. As for the square of CoP travel, it was not so strictly associated with its path length. For example, in 4 subjects of 10, in the condition EC/S (eyes closed) S has decreased, instead of being increased. This probably indicated inference of some unconsidered factor which helped these subjects to keep vertical stance in a more narrow circle of CoP with closed eyes. We assume, that elevated vigilance (agency) as reaction on eyes closing has probably helped subjects to perform this test more accurately. Interestingly, the CoP path length in these subjects was still longer than in the condition with eyes open. Such discrepancy, along with very big range of individual CoP square data prevented us of further calculation of sensory inputs contribution based on this parameter.

2. The "Walking test" group. The results for step length and knee elevation is presented in Table IV. The major result was that the sensory conditions EO/S and EC/F were significantly different between each other (p=0,001) for the right side, but that was not the case for the left side. This means that with closed eyes subjects walked on soft ground with shorter steps of the right leg, while steps of the left leg were rather uniform in the studied conditions. Also, steps of

the left side were generally more variable what was seen from bigger standard deviation of the step length.

Knee elevation was higher during walking on foam rubber in both legs. Eyes closing did not influence knee elevation during walking neither on solid nor soft ground (Table IV).

TABLE IV. STEP LENGTH AND KNEE ELEVATION UNDER STUDIED SENSORY CONDITIONS

Condition	Step length, right (mm)	Step length, left (mm)	Knee elevation, right (mm)	Knee elevation, left (mm)
EO/S	1080±78	1043±77	62±14	59±9
EC/S	1059±106	1079±141	61±11**	60±10**
EO/F	1058±172	1098±220	206±35**	199±34**
EC/F	1007±148**	1045±189	214±28**	215±35**
p Friedman	0,001	0,432	0,000	0,000

** - p <0,01 in comparison with the original sensory condition (EO/S)

Application of the above presented algorithm to the walking test showed following results (Tables V, VI). During walking the vestibular system's contribution was overwhelming with 0,93 for the right leg step length and almost 1,0 for that of the left leg (Table IV). Knee elevation presented a much higher contribution of the ground feature.

TABLE V. STUDIED SENSORY CONDITIONS AND CORRESPONDING SENSORY CONTRIBUTION DURING WALKING ACCORDING TO THE STEP LENGTH

Condition	$\mathbf{W}_{vest}$	$\mathbf{W}_{vis}$	$\mathbf{W}_{pro}$	Formula for net $\mathbf{W}$
Right leg step length				
EO/S	0,92±0,12	0,01±0,09	0,07±0,12	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro} = 1$
EC/S	0,93±0,15	0	0,07±0,15	$\mathbf{W}_{vest} + \mathbf{W}_{pro} = 1$
EO/F	0,99±0,07	0,01±0,07	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} = 1$
EC/F	1,0	0	0	$\mathbf{W}_{vest} = 1$
Right leg step length				
EO/S	1,00±0,21	0	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro} = 1$
EC/S	1,00±0,15	0	0	$\mathbf{W}_{vest} + \mathbf{W}_{pro} = 1$
EO/F	1,00±0,15	0	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} = 1$
EC/F	1,0	0	0	$\mathbf{W}_{vest} = 1$

TABLE VI. STUDIED SENSORY CONDITIONS AND CORRESPONDING SENSORY CONTRIBUTION DURING WALKING ACCORDING TO THE KNEE ELEVATION HEIGHT

Condition	$\mathbf{W}_{vest}$	$\mathbf{W}_{vis}$	$\mathbf{W}_{pro}$	Formula for net $\mathbf{W}$
Right leg step length				
EO/S	0,289±0,06	0,007±0,05	0,717±0,05	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro} = 1$
EC/S	0,287±0,06	0	0,713±0,05	$\mathbf{W}_{vest} + \mathbf{W}_{pro} = 1$
EO/F	0,99±0,14	0,01±0,14	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} = 1$
EC/F	1,0	0	0	$\mathbf{W}_{vest} = 1$
Right leg step length				
EO/S	0,278±0,05	0,01±0,36	0,721±0,06	$\mathbf{W}_{vest} + \mathbf{W}_{vis} + \mathbf{W}_{pro} = 1$
EC/S	0,278±0,15	0	0,722±0,05	$\mathbf{W}_{vest} + \mathbf{W}_{pro} = 1$
EO/F	0,97±0,18	0,3±0,18	0	$\mathbf{W}_{vest} + \mathbf{W}_{vis} = 1$
EC/F	1,0	0	0	$\mathbf{W}_{vest} = 1$

In general, these data prompt that ground features during walking exert notably stronger influence on step characteristics than vision, and during easy stance. The data also shows that steps with right side become shorter what in turn is indicative of more "cautious" and accurate stepping with the leading (right) leg. In a way, the right leg has probably played a role of a testing (sensing) instrument when walking.

V. CONCLUSION

The primary purpose of this study was to explore the feasibility of simple conventional tests (stabilographic and walking) to evaluate contribution of the 3 major sensory inputs to the body balance (the vestibular system, vision, proprioception) under vertical stance at ease (static balance) with stabilography, and during walking test (dynamic balance) with the motion video-capturing system, at acceptable quality. Our hypothesis, based on the literature data [5], was that in younger subjects proprioception would account for cal. 50% (or 0,5) of the net sensory contribution to the body balance.

We found that, in line with the hypothesis, the average contribution of the proprioceptory system to balance in younger subjects specifically under vertical stance was indeed cal. 0,5, while vision and the vestibular system accounted, almost equally, for 0,25 of it, each. However, that was the case only for one stabilographic metric, namely, the CoP path length. Computing of the velocity of the CoP travel did not add to the study, as it was very much the same with the CoP path length, presumably due to common origins of these signals (velocity is a time differential of path length). The CoP square was discarded from computation of the sensory input contribution as it was extremely variable, and its change was in some cases discordant with the change of the CoP path length. In general, our results stay in good line with the studies, which evaluate sensory contribution to motion [4], [5]. The novelty of our study largely lays in the aspects of simplicity and time-saving.

The walking test did not present valuable data in respect with the sensory input contribution to the net sensory control because the step length was rather stable across all sensory conditions, what is indicative of negligible role of vision and proprioception in the studied sensory conditions. Neither was informative the knee elevation height, because the texture of foam pad provoked subjects to elevate the knee higher to perform step, rather than to react on the texture of ground. In sum, during the walking test, proprioception was overwhelmingly prevalent in respect with the knee elevation height, and the vestibular system - in respect with the step length. This makes such walking test metrics non-informative of the sensory inputs contribution to motion.

Limitations to the study

In our model, the vestibular system was constantly functioning, as it was not possible to "switch it off". Neither we modulated it with rotation or vibration of the ground, as it needs technically complex approaches. As such, we had to extrapolate the vestibular sensory contribution by subtracting the visual and proprioception inputs from the net sensory control. Thus, in the present study evaluation of W of specific sensory inputs was methodologically based rather on evaluation of "functional loss", widely used in neurophysiology to judge on the functional significance of neural structures of the CNS, than on direct instrumented measurement of the function.

Additionally, the proprioceptive sensory input was presumably not fully abandoned in the present study. The foam pad helped rather abandoning the plantar exteroceptors than proprioception in general. As such, the orhanism experienced mostly the lack of sense of "support" [3].

Perspective and future studies

1. The obtained result looks promising for the aim of robust assessment of the sensory inputs contribution to motion and posture, especially for the pair "proprioception vs. vision". Theory predicts that during ageing contribution of the proprioceptory system to vertical stance would have been decreasing along with increasing of that of vision. Therefore, for future studies, we consider enrolling subjects of older ages (40-80 years) to test this assumption with our algorithm. Also, examination of patients with specific neurological symptoms, e.g. PD, cerebellum disorders, or dementia, would be helpful to sophisticate the presented algorithm.

2. Earlier, we launched a project on evaluation of rehabilitation potential of the modeled, ground-based microgravity (weightlessness) on patients with PD, with special focus on its effects on motion and cognition [10]. The outcome of the present study would have allowed evaluating the sensory-motor integration in PD patients and older people to know whether it is modified under artificial weightlessness? Our preliminary findings prompt that cognition in PD patients is improved under the program of modeled microgravity. This indicates on the possibility of more efficient sensory-motor integration in subjects with PD after application of microgravity. In turn, this would help elaborating prohylactic measures to assess, predict and, therefore, prevent their spontaneous falls in PD patients. The data obtained are important as it allow us rejecting such time-consuming, "science-intensive" methods, as motion video-capture, in favor of such robust, though enough fair, assessing methods, as the presented algorithm.

The study was financially supported by the Ministry of Science and Higher Education of Russian Federation (State Assignment, theme № 0752-2020-0007).III.

ACKNOWLEDGEMENT

The authors are grateful to the volunteers participated in the study.

REFERENCES

[1] S. Finnegan, K. Seers, and J. Bruce, "Long-term follow-up of exercise interventions aimed at preventing falls in older people living in the community: a systematic review and meta-analysis", *Physiotherapy*, vol. 105, pp. 187-199. doi: 10.1016/j.physio.2018.09.002. 2019.

[2] N. E. Allen, A. K. Schwarzel, and C. G. Canning, "Recurrent falls in Parkinson’s disease: A systematic review", *Parkinson's Disease,* vol. .2013. №906274. doi: 10.1155/2013/906274. 2013.

[3] A. Foisy, and Z. Kapoula, "Plantar cutaneous afferents influence the perception of subjective visual vertical in quiet stance", *Scientific Reports*, vol. 8, №14939. doi: 10.1038/s41598-018-33268-3. 2018.

[4] K. J. Feller, R. J. Peterka, and F. B. Horak, "Sensory re-weighting for postural control in Parkinson’s disease", *Frontiers in Human Neurosciences*, vol. 13, №126. doi: 10.3389/fnhum.2019.00126. 2019.

[5] R. J. Peterka, "Sensorimotor integration in human postural control", *Journal of Neurophysiology*, vol. 88, pp. 1097-1118, DOI: 10.1152/jn.2002.88.3.1097 2002.

[6] P. F. Smith, "Vestibular functions and Parkinson's disease", *Frontiers in Neurology*, vol. 9. №1085. doi: 10.3389/fneur.2018.01085., 2018.

[7] M. Jaime, J. Longard, and C. Moore, "Developmental changes in the visual-proprioceptive integration threshold of children", Journal of Experimental Child Psychology, vol. 125, pp. 1-12. doi: 10.1016/j.jecp.2013.11.004. 2014.

[8] D. Riva, C. Mamo, M. Fanì, P. Saccavino, F. Rocca, M. Momenté, and M. J. Fratta, "Single stance stability and proprioceptive control in older adults living at home: gender and age differences", *Aging Researches*, vol. 3, № 561695. doi: 10.1155/2013/561695. 2013.

[9] B. M. Sexton, Y. Liu, and H. J. Block, "Increase in weighting of vision vs. proprioception associated with force field adaptation", *Scientific Reports*, vol. 9, №10167. doi: 10.1038/s41598-019-46625-7. 2019.

[10] A. Meigal, L. Gerasimova-Meigal., I. Saenko, and N. Subbotina. "Dry immersion as a novel physical therapeutic intervention for rehabilitation of Parkinson’s disease patients: a feasibility study", *Phys. Med. Rehab. Kuror.* vol. 28, pp. 275-281. doi: 10.1055/a-0577-5139. 2018.