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Review

Functionally Directed Balance Testing: Are Task–Oriented Balance Testsa Future?

Erika Zemková

Department of Sports Kinanthropology, Faculty of Physical Education and Sport Comenius University in Bratislava, Bratislava, Slovakia

ABSTRACT

This paper deals with static and functionally directed balance testing. Traditionally, static posturography has been used to assess postural stability under various conditions. Though such assessment has shown sufficient reliability of repeated measurements, there has been a problematic discrimination regarding individuals with different levels of balance capabilities, and its ability to detect slight changes in postural control system after intervention. Recently, task-oriented balance tests in form of visually-guided center of mass (COM) target-matching task and visually-guided COM tracking task have become a part of the test battery evaluating the efficiency of athletic training and rehabilitation. These tests have been found sensitive enough to reveal differences within and between groups, as well as changes in the postural control system after different forms of exercise programs. Findings gained in the field of sport and rehabilitation can be explored in clinical medicine and physical therapy. This also supports future research toward exploring novel alternatives of functional balance assessment.

Key words: *functional balance, static posturography, training, visual feedback*

Introduction

Traditionally, postural stability has been evaluated under static conditions. However, static posturography in most of the cases has been found not sensitive enough to differentiate between individuals with different levels of balance capabilities. Lower sensitivity of static posturography is a consequence of multiple sensory inputs (visual, vestibular, and proprioceptive) involved in postural control. Such a system can compensate for a smaller impairment of balance in such a way that under normal conditions (quiet stance) no deficits in postural stability may be apparent. Under dynamic conditions (stance on an unstable surface), the control mechanisms are taxed to a substantially higher extent so that individual differences can be revealed.

However, regardless of the variety of currently available dynamic posturography systems, most of them have shortcomings. First, some of the platforms, although capable of producing even very large and fast motion, are insufficient to destabilize the subject beyond the stability limit. Whilst very suitable for the elderly and patients with deteriorated coordination, in highly skilled athletes they do not cause serious balance impairments. Second, many of them produce only unidirectional movements, usually in the antero-posterior plane. Furthermore, in some cases the learning effect has been observed when using tilted platforms due to the subjects' relatively high predictability as to upcoming perturbations.

To avoid these drawbacks, more sophisticated methods have been proposed, closer to the balance function. Task-oriented balance tests, such as a visually-guided COM target-matching task or a visually-guided COM tracking task seem to be more promising.[1] In the first case, the subjects have to hit the target randomly appearing in one of the corners of the screen by a horizontal COM shift in the appropriate direction while standing on a spring-supported platform equipped with a computer-based system used for feedback monitoring of the COM movement (Figure 1). The system registers the time, distance, and velocity of the center of pressure (COP) trajectory between the appearance of the stimulus and its being hit by a horizontal COM shift. In the second, the subjects are provided with feedback on the COM displacement on a computer screen while standing on a force platform (Figure 2). Their task is to trace, by shifting their COM, a curve flowing

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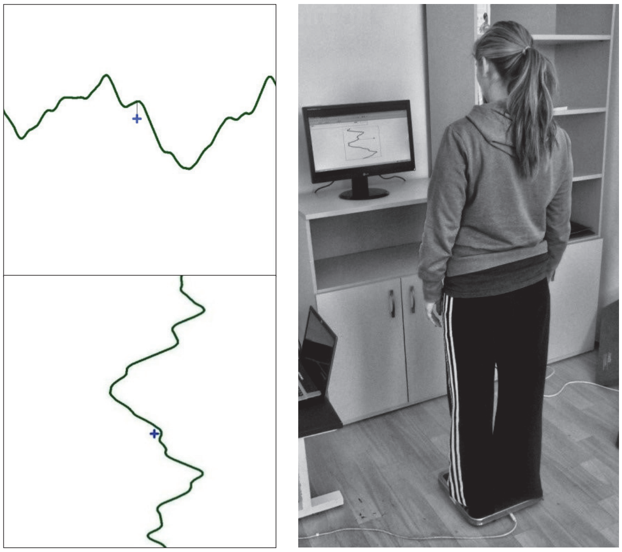

Fig. 1. (a) Visually-guided COM target-matching task while standing on either (b) force plate or (c) spring-supported platform.

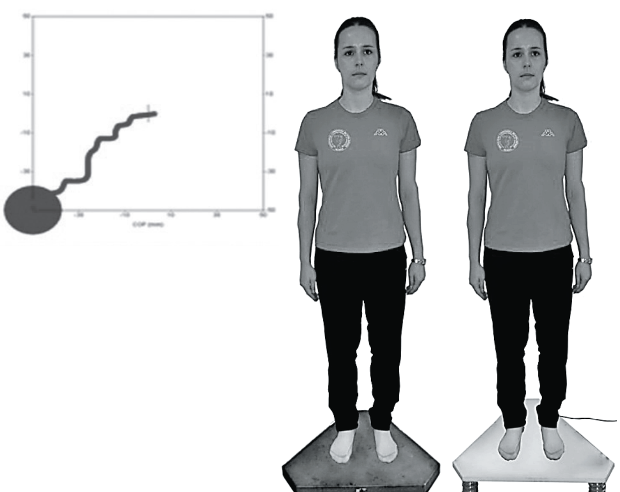

Fig. 1. Visually-guided COM tracking task in (a) antero-posterior and (b) medio-lateral direction while standing on (c) portable force plate.

either in horizontal or vertical direction. The deviation of an instant COP position from the curve is recorded at 100 Hz by means of the FiTRO Sway Check system (FiTRONiC, Slovakia).

Reliability and methodological issues of task-oriented balance tests

The analysis of repeated measurements showed test-retest correlation coefficients and measurement errors of 0.81 and 8.8% for the visually-guided COM target-matching task and 0.83 and 7.0% for the visually-guided COM tracking task.[2] Thus, the reliability of task-oriented balance tests is comparable to static balance tests, however with better potential for differentiation between groups with different levels of balance capabilities.[3]

This can be documented by one of our studies that showed no significant differences in parameters of balance registered during quiet standing between dancers, students and older women.[2] On the other hand, the mean COP distance from both horizontally and vertically flowing curves was significantly lower in dancers than in students and older women. These findings indicate that for some athletes, untrained subjects and elderly people, the task-oriented balance tests might represent a more sensitive and therefore more appropriate method, allowing better discrimination of individuals of different ages and performance levels than the evaluation of postural stability under static conditions.

However, attention should be paid to the velocity and positioning of the curve tracking by a visually-guided COM. We found no significant differences in the COP distance from a horizontally and vertically flowing curve at the velocity of 0.93 $cm.s^{-1}$ in older women, healthy young adults, and dancers.[2] Such a slow curve velocity was probably very easy to trace for all subjects examined. However, the values were significantly higher in older women and healthy young adults than in dancers while tracing a curve flowing at the velocity of 1.85 $cm.s^{-1}$. Further increase in the curve velocity to 2.77 $cm.s^{-1}$ did not show significant differences in the mean COP distance from the curve in either antero-posterior (A-P) or medio-lateral (M-L) direction when compared to the values obtained at the velocity of 1.85 $cm.s^{-1}$. In particular, dancers were able to perform a visually-guided COM tracking task with similar accuracy under any velocity conditions. This effect may be ascribed to better proprioceptive acuity of dancers due to sport-specific adaptation.

On the other hand, when we compared the accuracy of visual feedback control of COP movement in A-P and M-L directions in athletes of different specializations, the COP distance from both horizontally and vertically flowing curves was only slightly lower in competitors in snowboarding, windsurfing and karate as compared to cyclists and rowers.[4] For these athletes, it is likely that the regulation of the COM movement based on visual feedback of its position on a computer screen did not represent a typical form of body control. Therefore, in order to obtain balance parameters relevant to most free-style sports, the task close to the one used during training or competition should be preferred. For such highly-skilled athletes, dynamic posturography seems to be a more sensitive method reflecting their sport-specific adaptation.[5]

Nevertheless, a visually-guided COM tracking task might be an appropriate alternative for individuals after lower limb injury, namely in an early phase of rehabilitation when effusion and pain in the joint can make it particularly sensitive to movement perceived as possibly aggravating that injury. Indeed, the mean COP distance from the curve was significantly higher in the A-P than the M-L direction when performing the test on the injured leg, whereas its values did not differ significantly between both directions while standing on the non-injured leg.[4] In addition, these differences were more pronounced on the ankle than the knee injured leg. As the regulation of the body position in the A-P direction is provided predominantly by an ankle strategy, an increase in the threshold of perception of the ankle movement due to injury may be assumed. It is known from physiology that this effect can be mainly ascribed to the decreased sensitivity of the receptors around the joint. Resulting partial reduction of afferent impulses leading to deterioration in the proprioceptive feedback control of balance after injury most likely contributed to the less precise perception of the COM position and the regulation of its movement in the A-P direction.

It is also known that when the reliability of proprioceptive information is reduced, either by standing on a sway-referenced surface[6] or on a compliant foam surface[7], there is an increased attention demand associated with maintenance of balance. Particularly, vision is of greater relevance when the demands on postural task are increased.[8,9] According to Taube et al.[10] there is a significant interaction between the visual and the support surface conditions indicating that the H-reflex is more strongly affected by changes in visual feedback while standing on an unstable surface.

In our experiment, the deprivation of visual control and the reduced stance support led to a significantly higher mean distance from the middle of COP as compared to standing on a stable surface with eyes closed.[11] Its values were also significantly higher while standing on a foam surface with eyes open than on a firm support base with eyes open. On the other hand, there were no significant differences in the mean COP distance from the curve while performing a visually-guided COM tracking task on stable and foam surfaces. In addition, postural control was more compromised in the A-P than in the M-L direction during the task-oriented balance test, whereas opposite was true for quiet standing. It may be assumed that visual feedback compensates for reduced proprioceptive information while standing on a foam surface.

Furthermore, there were no significant differences in the mean COP distance from the horizontally and vertically flowing curve while standing on stable and foam surfaces.[11] However, its values were significantly higher in the A-P than the M-L direction when the test was performed on a spring-supported platform. A combination of the spring-supported platform and foam showed the same tendency but its values were only slightly higher than during standing on the spring-supported platform. These differences were mainly due to increased the COP distance from the horizontally flowing curve. It means that dynamic conditions better differentiate balance parameters in A-P and M-L directions during a visually-guided COM tracking task.

These findings indicate that providing visual feedback in more demanding and functional balance tasks (e.g., the stance on a spring-supported platform) may represent a more appropriate alternative to a stance on a stable force plate. Another unique feature of these task-oriented balance tests is that voluntary feedback can be provided under two different conditions. First, the subjects can concentrate on a particular part of the action (e.g., hitting the target) or focus on the movements themselves (e.g., the positioning of the COM). This approach may allow evaluating different aspects of postural control, which is of importance for the conception and evaluation of visual feedback interventions.

Task-Oriented Balance Tests in Assessment of Acute and Adaptive Changes in Sensorimotor Functions after Interventions

Visually-guided COM tracking task

In one of our studies, the accuracy of visual feedback control of COP movement in A-P and M-L directions over repeated trials was evaluated.[12] Subjects were provided with feedback on COM displacement on a computer screen while standing on a dynamometric platform. Their task was to trace, by shifting COM, a curve flowing either in vertical or horizontal direction. The test consisted of twenty 30-second trials randomly performing in each direction. After its completion, an additional 6 trials (one for each direction) were performed every 5 minutes. The deviation of instant COP position from the curve was recorded at 100 Hz by means of the FiTRO Sway Check (FiTRONiC, Slovakia). The distance of sway trajectory from the curve decreased in both A-P and M-L directions when repeatedly performing a visually-guided COM tracking task. However, a significant improvement was observed only during the initial seven trials. After cessation of practice its values slightly decreased over a period of 10 minutes and then gradually increased toward 30 minute of recovery. Such a temporary improvement of visual feedback control of body position may be ascribed to a) improved ability to more precisely perceive COM position through use of proprioceptors, b) improved motor ability to perform more accurate body movement, and/or c) improved »proprioceptive memory« with repeated trials. As the tracing randomly flowing curves by visually-guided COM movement on the screen most likely eliminates the potential confounding factor of proprioceptive memory, this effect may be attributed mainly to the improvement of sensorimotor functions. Though it is not possible to separate the sensory and motor part of this task, one may expect mainly improvement of proprioceptive acuity with practice. It is because the same receptors share the weight transmission from one leg to another; namely during regulation of COM movement in the medio-lateral direction (cutaneous and GTO receptors) and discrimination of the ankle joint position, namely during regulation of COM movement in the antero-posterior direction (muscle spindle and cutaneous receptors). However, further studies are needed to prove this assumption. Our study showed that task-oriented sensorimotor exercise temporarily improves the accuracy of visual feedback control of COP movement in both the A-P and M-L directions.

In order to evaluate the accuracy of visual feedback control of body position under static and dynamic conditions, we compared mean COP distance from vertically and horizontally flowing curves during a visually-guided COM tracking task while standing on stable and unstable surfaces, respectively. The distance of sway trajectory from the curve registered while standing on a stable platform decreased from the 1st to the 8th trial with no further improvement up to the 20th trial. On the other hand, its values registered under dynamic conditions gradually decreased from the 1st to 20th trial. Consequently, there was a greater decline in its values over repeated trials (26.3% and 46.1%, respectively). This effect is very probably due to more efficient regulation of COM movement primarily by rotation of the ankle joints when standing on an unstable platform. These findings indicate that the learning effect is greater when performing visually-guided COM tracking tasks under dynamic than under static conditions.

Another study evaluated the effect of 12-week conventional and task-oriented sensorimotor training on visual feedback control of the body position in individuals with functional disbalances.[12] The training during the initial four weeks consisting of conventional exercises (4 sessions per week) was for the following eight weeks supplemented by visual feedback exercises (2 of 4 sessions per week). The COP distance from the horizontally and vertically flowing curve measured during a visually-guided COM tracking task only slightly decreased (8.7%) in the initial four weeks. However, its greatest decline was observed from weeks 5 to 8 (10.6%) and from weeks 9 to 12 (14.5%), when visual feedback exercises were included into the training program. A similar trend was observed in the case of a visually-guided COM target-matching task. However, there were significant individual differences. The subject with good initial performance learned faster as compared to the one with slower response time and longer distance of sway trajectory registered prior to the training (29.3% and 17.0%, respectively). Contrary to this, there were no significant changes in the parameters of balance registered in static conditions with or without visual control. Altogether, a conventional training program consisting of balance exercises does not improve visual feedback control of the body position. Providing visual feedback of the COM movement on a computer screen during training contributes to more precise perception of the COM position and regulation of its movement during different task-oriented sensorimotor exercises. These findings are in agreement with an earlier study by Gibson[13] who documented that practice with some type of reinforcement (e.g., visual or auditory feedback) resulted in greater perceptual improvements. However, the role of visual feedback exercises in the facilitation of learning of other skilled movements and the enhancement of functional outcomes remained unclear.

Task-oriented balance tests can be also incorporated into the post-rehabilitation program consisting of balance exercises for athletes after lower limb injuries in order to speed up their return to competition. We evaluated the effect of 12 weeks of combined balance and resistance exercises (e.g., semi-squats, deep squats, wide-stance squats, one-legged squats, barbell squats performed on various unstable surfaces) on neuromuscular performance in soccer players after anterior cruciate ligament (ACL) reconstruction.[14] Pre-training measurements (after a conventional rehabilitation program) showed non-injured-to-injured leg percentage differences of 15.7% for static and 24.5% for dynamic balance. Following the training, there were no significant changes in static balance while standing on both legs, on the non-injured or on the injured leg. Likewise, the dynamic balance did not change significantly while standing on both legs and on the non-injured leg; however significantly improved on the injured leg. In addition, the COP velocity significantly decreased during the bipedal stance on a platform tilted in the M-L direction, but not when tilted in the A-P direction. These findings indicate that resistance exercises performed on unstable surfaces represent an effective means for the improvement of dynamic balance under various conditions in athletes after ACL injury.

Another study by Vlašič[15] showed that 12 weeks of balance training in athletes with previous ACL injury improved postural stability during stance on the injured leg and on both legs with eyes open as well as eyes closed. Better COM control and its regulation in the A-P direction during a visually-guided COM tracking task was also observed. On the other hand, there were no significant changes in balance parameters under these conditions in the group performing the same exercises on a stable support base. (Table 1)

Visually-guided COM target-matching task

The following study evaluated the accuracy of visual feedback control of body position during a task-oriented sensorimotor exercise and its effect on static and dynamic balance.[16] The task of the subjects was to hit the target randomly appearing in one of the corners of the screen by horizontal shifting of COM in an appropriate direction while standing on an unstable spring-supported platform equipped with a PC system for feedback monitoring of COM movement. The test consisted of 20 sets of 60 stimuli with a 2 min rest in-between. Time, distance, and velocity of COP trajectory between stimulus appearance and its hit by visually-guided COM movement on the screen were registered by means of the FiTRO Sway Check (FiTRONiC, Slovakia). The response time and distance of sway trajectory between stimulus appearance and its hit by visually-guided COM movement on the screen decreased and sway velocity increased with repeated trials. Such faster responses to visual stimuli may be ascribed to more precise perception of COM position and regulation of its movement by horizontal shifting of COM in an appropriate direction according to the position of stimulus on the screen. However, practice of the visually-guided COM target-matching task was not beneficial for improvement of postural stability under static and dynamic conditions. It means that task-oriented sensorimotor exercise acutely enhances visual feedback control of body position but not static and dynamic balance.

TABLE 1
CHANGES IN PARAMETERS OF BALANCE AFTER DIFFERENT FORMS OF INTERVENTION

Tests	Parameters	Task-oriented balance exercises	Intability resistance exercises
Static balance test	Mean COP velocity (mm/s)	n.s.	↓*
	Mean trace length of the COP in Y-axis (mm)	n.s.	–
	Mean trace length of the COP in X-axis (mm)	n.s.	–
	Mean trace length of the COP in Y-axis (mm)	n.s.	–
Dynamic balance test	Mean COP velocity (mm/s)	–	↓**
	Mean distance from the middle of COP (mm)	–	n.s.
	Mean trace length of the COP in X-axis (mm)	–	↓*
	Mean trace length of the COP in Y-axis (mm)	–	n.s.
Visually-guided COM tracking task	Mean COP distance from horizontally flowing curve (mm)	↓*	↓*
	Mean COP distance from vertically flowing curve (mm)	↓*	–
	Mean squared COP distance from horizontally flowing curve (mm^2)	↓*	–
	Mean squared COP distance from vertically flowing curve (mm^2)	↓*	–

*p ≤ 0.05, **p ≤ 0.01

In view of this, our other study evaluated the effect of 3-week task-oriented sensorimotor training on neuromuscular performance in recreationally-active individuals.[17] They underwent 3-times a week exercises in the form of a visually-guided COM target-matching task (3 sets of 200 stimuli with 5 min rest in between). The response time significantly decreased after training. Although at the same time the distance of the sway trajectory also significantly decreased, sway velocity significantly increased. Substantial improvement took place during the initial 6-8 sessions. Also the ability to maintain balance on an unstable platform significantly improved. However, there were no significant changes in the COP velocity registered in static conditions. Nevertheless, the task-oriented sensorimotor exercise applied represents a suitable means for enhancing neuromuscular performance enabling more rapid postural sway adjustments in altered surface conditions.

On the other hand, 8-week training consisting of balance exercises performed simultaneously with reaction tasks showed an improvement in dynamic balance, namely when responding to visual stimuli, in recreationally-active individuals.[18] However, there were no significant changes in the COP velocity registered in static conditions with eyes open and eyes closed. Such training was not even efficient in improving visual feedback control of body position during a visually-guided COM target-matching task.

Overall, these studies indicate that task-oriented sensorimotor exercises represent a more effective means for improvement in both reflexive responses of balance and voluntary movement compared with performing a second-

TABLE 2
CHANGES IN PARAMETERS OF BALANCE AFTER DIFFERENT FORMS OF INTERVENTION

Tests	Parameters	Task-oriented balance exercises	Combined agility-balance exercises
Static balance test	Mean COP velocity (mm/s)	n.s.	n.s.
	Mean distance from the middle of COP (mm)	n.s.	n.s.
	Mean trace length of the COP in X-axis (mm)	n.s.	n.s.
	Mean trace length of the COP in Y-axis (mm)	n.s.	n.s.
Dynamic balance test	Mean COP velocity (mm/s)	↓**	↓**
	Mean distance from the middle of COP (mm)	n.s.	↓*
	Mean trace length of the COP in X-axis (mm)	↓*	↓*
	Mean trace length of the COP in Y-axis (mm)	↓*	↓*
Visually-guided COM target-matching task	Response time (ms)	↓**	n.s.
	Mean COP distance covered (mm)	↓*	n.s.
	Mean COP velocity (mm/s)	↑*	n.s.

*p ≤ 0.05, **p ≤ 0.01

ary reaction task concurrently with balance exercises. (Table 2)

Task-oriented balance tests have also been found sensitive to reveal post-training changes in postural control system in competitive athletes. Macko[19] evaluated the effects on balance after 12-week training which consisted of different forms of exercises eliciting predominant instability of either upper or lower body in karate competitors. The COP velocity under different standing conditions (Heiko-dachi, Neko-ashi-dachi, and one-legged stance) decreased more profoundly in Group 2 (G2) that used an Aquahit bag than in Group 1 (G1) that exercised on a Bosu ball. On the other hand, dynamic balance measured by the MFT S3 diagnostic system improved in G1 exercising on the Bosu ball more than in G2 using the Aquahit in both A-P and M-L planes in Heiko-dachi and Sanchin-dachi stances. However, there were more profound decreases in the mean COP distance from the horizontally flowing curve (regulating the COM movement in A-P plane) in G2 using the Aquahit, and from the vertically flowing curve (regulating the COM movement in M-L plane) in G1 exercising on the Bosu ball. Furthermore, the sway trajectory distance between the appearance of the stimuli on the screen and the hit by a horizontal COM shift decreased more profoundly in G1 exercising on the Bosu ball than in G2 using the Aquahit. This study demonstrated that both training means significantly improve postural stability but the gains are task-specific in terms of better static balance with the Aquahit and better dynamic balance with the Bosu ball. This effect can also be seen in the accuracy of visual feedback control of the COP movement in A-P and M-L directions (the Aqauhit and the Bosu ball, respectively) and more precise perception of the COM position and better regulation of its movement in the required direction (the Bosu ball).

More information on balance testing and training can be found in the invited review »Assessment of balance in sport: Science and reality«[20] and a book chapter »Sensorimotor exercises in sports training and rehabilitation«[21].

Conclusions

Both instability agility and resistance exercises may be applied to improve the balance performance in athletes and physically active subjects. On the other hand, visual feedback exercise seems to be a promising tool for retraining balance after lower limb injury, which could complement the existing rehabilitation methods. It also may be of potential use in the elderly population for reducing the risk of falling and its health-related consequences. The comparison of balance parameters before and after an exercise program may not only provide information on physiological adaptations (e.g., the improvement of proprioceptive functions) but also on mechanical changes in the technique (e.g., regulation of COM movement with more precision but less effort). This highlights the importance of implementing the principle of specificity in balance testing, not only in sport but also in rehabilitation settings.

Task-oriented balance tests have been found sensitive in discriminating between groups with different levels of balance capabilities, as well as to reveal changes after different forms of exercise programs. Therefore, future work should be directed toward exploring novel alternatives of balance measurements during functional tasks. Accelerometry may be a valid quantitative measure of postural sway that is more strongly related to task-based assessment. The implementation of accelerometry in combination with stochastic dynamics may allow quantification of the time-varying structure of postural sway patterns. Such diagnostic tools may be implemented not only in laboratory but also in field-testing of balance under various conditions.

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E. Zemková

Department of Sports Kinanthropology, Faculty of Physical Education and Sport, Comenius University in Bratislava, Nábr. arm. gen. L. Svobodu 9, 814 69 Bratislava, Slovakia
e-mail: erika.zemkova@uniba.sk

FUNKCIONALNO USMJERENO TESTIRANJE RAVNOTEŽE: JESU LI TESTOVI USMJERENI NA ZADATKE BUDUĆNOST?

S A Ž E T A K

Rad razmatra statičko i funkcionalno testiranje ravnoteže. Statički položaj tijela se tradicionalno upotrebljava za procjenu tjelesne stabilnosti u različitim uvjetima. Iako je ponovljenim mjerenjima utvrđena dovoljna pouzdanost takve procjene, ona ne omogućava razlikovanje pojedinaca s različitim razinama sposobnosti za uspostavljanje ravnoteže i otkrivanje malih promjena u kontroli ravnoteže nakon zahvata. Nedavno su u bateriju testova za procjenu efikasnosti sportskog treninga i rehabilitacije uključeni i vizualno vođeni testovi ravnoteže usmjereni na zadatke (COM). Pokazalo se da su ti testovi osjetljivi na razlike unutar i između skupina, kao i na promjene u sustavu tjelesne kontrole nakon različitih programa vježbanja. Ovi rezultati postignuti u području sporta i rehabilitacije mogli bi se ispitati i u kliničkoj medicini i fizikalnoj terapiji u okviru budućih istraživanja novih oblika procjene funkcionalne ravnoteže.