Assessment of the Functional Movement Screen Test With the Use of Motion Capture System by the Example of Trunk Stability Push-Up Exercise Among Adolescent Female Football Players

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Abstract

The paper presents the application of the BTS motion capture system to verify the FMS test assessment. The research group consisted of adolescent female football players who underwent standard FMS assessment by a physiotherapist. In order to objectify the physical performance assessment, a mechanical model was proposed, on the basis of which the parameters supporting the evaluation of the test were defined. The example of the analysis of one of the exercises (push-ups) presented in the paper showed that even the players who obtained the highest marks in the test do not always perform the exercises flawlessly, which is a consequence of subjective assessment made by specialists. The use of a motion capture system together with an appropriate biomechanical model allows for a much more objective assessment of the physical performance and detecting any dysfunction of the movement apparatus of the examined persons.

Keywords: human motion, motion capture, Functional Movement Screen, female football

1. Introduction

The Functional Movement Screen (FMS) is used to identify asymmetry and deficiencies in functional movement, which can increase the injury risk. They are commonly used to assess the physical performance of athletes in order to better plan training or to recover faster after an injury. The FMS consists of 7 simple exercises performed in a given sequence, which are assessed by the physiotherapist. This assessment is very subjective, it depends on the experience of the specialist assessing the test, his perceptiveness, but also on whether he positions himself correctly during the examination, which ensures a better assessment of e.g. geometry of the body during some exercises. The FMS assessment often influences the further course of the rehabilitation or training process in athletes. It has been demonstrated that professional football players who scored less than 14 points on the FMS™ had a greater risk of suffering a serious injury [1]. Therefore, it is very important to assess the FMS as objectively as possible, which is possible only thanks to modern motion analysis systems.

Motion capture systems are used to track and record human motion in real time. This allows the analysis of physical condition, injury mechanism, prevention and rehabilitation. Motion capture systems are widely used in many sport disciplines [3], prosthesis designing [7, 8], prediction of athletes results or even human identification problems [9, 10]. There are also several publications on the use of motion capture system to the FMS assessment system.

The goal of [2] study was to assess differences between the classification with three-point scale (rate of 0 wasn't taken into consideration) during the deep squat movement. Twenty-eight participants (9 male and 19 female) were divided into three groups. These groups were determined based on the FMS evaluation. After group allocation, in order to collect motion data, participants were asked to perform a deep squat according to the FMS guideline. During the trial, markers placed on the participant's body, were recorded using VICON MX motion analysis camera. Simultaneously, ground force data were collected by force plate. This study shows that mechanics of lower extremity is different between the various levels, determined by the FMS test of the deep squat. However, during this study only examination of the lower limbs were included, excluding the spine and upper limbs [2]. Motion capture software was also used in study [4]. Participants recruited in this research were 12 volleyball players and 12 track and field athletes. Their movement while performing the FMS was captured by two webcams, further through self-written program values of angles achieved in joints by the assumes were obtained. This study provides more available and unexpansive way of using motion capture systems in biomechanical studies [4].

Described examples of studies regarding the FMS and use of motion capture systems show that to obtain accurate results of the FMS test it is necessary to include motion capture systems into the test protocol.

In this study, the FMS test was taken with the use of BTS System including six cameras tracking passive markers attached to assume body prominences and two force plates. In order to assess quality of performing movement, for each of exercises included in the FMS various parameters were specified based on proposed biomechanical model of the body.

Main goal of the paper was to propose the approach that allows assessing the participant with the original four-point scale in combination with usage of motion capture system provides more objective rating of performed movement.

2. Methods

2.1 Participants

The participants of this study were 7 female football players aged 13,60 ± 1,05 years. The average body weight was 46,14 ± 8,25 kg and the body height was 157,86 ± 7,22 cm. None of the players who took part in the study indicated any contraindications to its performance, nor did they report any injury or pain. Each of the players performed 7 exercises of the FMS test. Before the test, the legal representative of each player signed an informed consent to participate in a study. The Ethics Committee's approval was issued by Bioethical Committee working by Poznan University of Medical Sciences.

2.2 Functional Movement Screen™ (FMS)

The FMS test is a set of 7 tests performed in order to identify deficient areas of mobility and stability in the professional or amateur athletes. Visible compensation in individual movement or instability in subsequent movement tasks influence movement pattern quality and decreases the grade of assessed patient. During each of seven exercises, the subject makes 3 repetitions, the best of which result is evaluated. The individual achieves the highest score (three points) while performing the exercise correctly. Two points are given for the exercise with movement compensation. When a patient is not able to perform an exercise, then only one point is given. However, if pain occurred during the attempt to perform the exercise, then the score is zero [5].

The FMS test consists of the following movement patterns [5,6]:

- deep squat,
- hurdle step,
- in-line lunge,
- shoulder mobility,
- active straight leg raise (ASLR),
- trunk stability push-up,
- rotary stability.

In this article we will focus on trunk stability push-up exercise, that has been analysed with the use of an optoelectronic motion capture system. In this exercise the subject makes the push-up starting from the prone position to the support position. The aim of this exercise is to assess the ability to hold stable torso in the sagittal plane during symmetrical shoulder work.

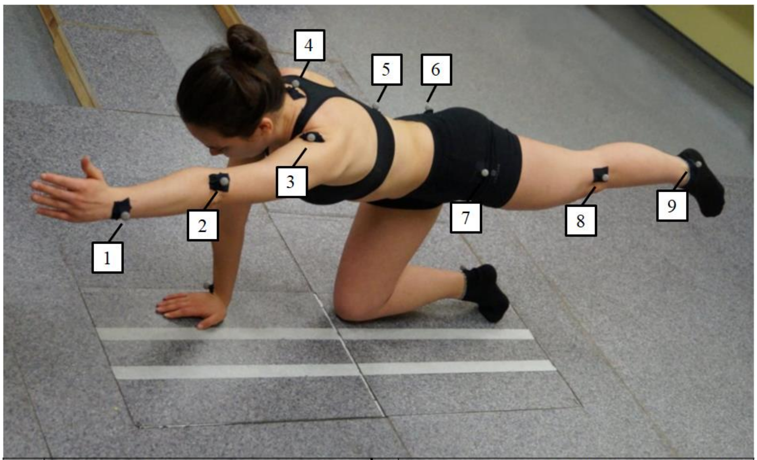
The FMS test requires special equipment, involving: base with dimensions 5x15x150 cm, elastic gum, one long measuring stick and two crossbars.

2.3 Experimental protocol.

In our research the BTS Smart-Dx was used together with two dynamometric platforms with the 400 Hz sampling rate. In order to record proper data passive markers were attached to skin with stripes of kinesiology tape, enabling markers to stay in place with no need to reattach them during examination. Markers were placed by physiotherapist in chosen anatomical landmarks, to capture points necessary for later data analysis. Scheme of markers location is shown in the Figure 1.

Whole seven FMS tasks were performed in a sequence recommended by the original protocol. Before each exercise participants were familiarized with the tasks they would be asked to perform. In case of deep squat, hurdle step, in-line lunge and rotary stability tasks, force plates were used.

All participants were rated with the standard FMS scale by the same physiotherapist at the same time when the kinematic and dynamic data were recorded.



no.	bony prominences		
1	styloid process of radius (SPR)	5	spinous process of the Th12 vertebra (Th12)
2	lateral epicondyle of the humerus (LEH)	6	Sacrum (Sacrum)
3	the acromion of the scapula (AS)	7	greater trochanter of the femur (GTF)
4	spinous process of the C7 vertebra (C7)	8	lateral epicondyle of the femur (LEF)
		9	lateral malleolus (LM)

Figure 1. Scheme of location of passive markers on the participant's body during rotary stability exercise

3. Data processing

The obtained data were processed in order to prepare them for further calculations. Recorded 3D points were ascribed to the previously prepared model, using Smart Tracker software. Afterwards, the kinematic data were interpolated and smoothed with the Smart Analyzer software. A cubic spline curves were used to interpolate signal and then the signal was smoothed using a triangular window filter. This allowed to reduce the influence of disruptions on the test result. Each of the defined parameters for seven test tasks were calculated with the use of Smart Analyzer and MATLAB software.

For trunk stability push-up exercise following parameters were defined:

- uniform torso movement (UTM),
- abduction of the shoulder (δ),
- the initial and final differences between abduction in the shoulders (ID/FD),
- spine side flexion (SF),
- maximum extension degree in elbow joint (ε).

Uniform torso movement (UTM) – parameter determines, if the subject lifts and lowers the torso as one segment or there is a difference between movement of torso parts, e.g., poorly performed exercise is when the upper part of the torso is lifted or lowered as first segment, then the patient moves middle part of the thorax and in the end the lower part is lifted or lowered. To calculate this parameter, three angles (α, β and γ) were defined, as shown in the Figure 2. The angles β and γ were defined in the same way as α, but for Th12 and Sacrum, respectively. In further calculations, projection of the angles on plane XY was used and the following vectors were defined: $\overrightarrow{\mathrm{LC}}$ – vector led from middle between projection LM of right and left lower limb on plane XZ to C7, $\overrightarrow{\mathrm{LC_{XZ}}}$ – vector led from middle between projection LM of right and left lower limb on plane XZ to projection of C7 on plane XZ.

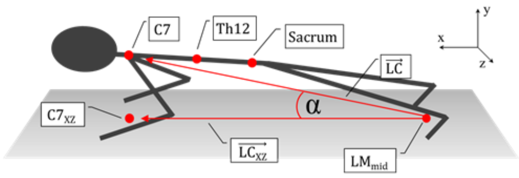


Figure 2. Track points and vectors defined for uniform lifting and lowering the torso

The value of the UTM parameter is calculated as mean of standard deviations from angular velocities calculated based on changes in the values of the angles α, β and γ, in a particular time frame, separately for phase of lifting and phase of lowering the torso, according to the following equations:

$$\bar{\omega}_i = \frac{\omega_{\alpha_i} + \omega_{\beta_i} + \omega_i}{3}, \tag{1}$$

$$UTM_i = \sqrt{\frac{\left(\omega_{\alpha_i} - \bar{\omega}_i\right)^2 + \left(\omega_{\beta_i} - \bar{\omega}_i\right)^2 + \left(\omega_{\gamma_i} - \bar{\omega}_i\right)^2}{3}}, \tag{2}$$

$$UTM = \frac{\sum_{i=1}^{m} UTM_i}{m}, \tag{3}$$

where $\bar{\omega}_i$ is an arithmetic average of the angular velocities (ω_{α_i}, ω_{β_i} and ω_{γ_i}) in the ith time frame [deg/s], ULT_i is standard deviation of the angular velocities in the ith time frame [deg/s] and ULT is mean standard deviation (mean ULT_i), which is the final value of the ULT parameter [deg/s], m is the number of the time frames. Application of this equations allow to measure the difference between angular velocities of subsequent parts of the torso's movement. While performing Trunk Stability Push-Up correctly, value of this parameter should be equal or as close as possible to 0. Small values of UTM parameter indicate that the torso is lifted as a unit.

Abduction of the shoulder (δ) – during performance of trunk stability push-up patient may relocate centre of the body weight in order to make lifting easier, what can be obtained by abduction in the shoulder. δ was defined as an angle between arm and sagittal plane and was measured as an angle between the LEH, C7 and Th12 points projected on the support plane XZ, as shown in the Figure 3. For this parameter, the following vectors were defined: $\overrightarrow{\mathrm{CL}_Z}$ – vector led from projection of C7 on XZ plane to projection of LEH on XZ plane, $\overrightarrow{\mathrm{CT}_{\mathrm{XZ}}}$ – vector led from projection of C7 on XZ plane to projection of Th12 on XZ plane.

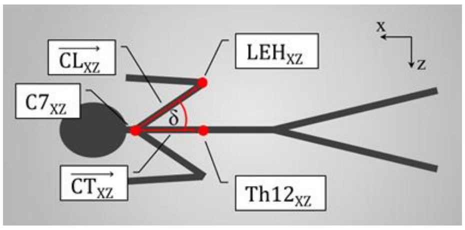


Figure 3. Track points and vectors defined for abduction in shoulder joint

The initial and final differences between abduction in the shoulders (ID/FD) - parameter determines changes in value of abduction in shoulders between the right and left upper limb for initial and final position of the patient during the phase of lifting and lowering the torso. To determine initial and final differences, the subtraction between value of δ angle for right (δ_R) and left (δ_L) upper limb was calculated as:

$$ID/FD = \delta_R - \delta_L. \tag{4}$$

Small values of ID/FD parameter stands for good performed exercise where position of the patient (abduction of the shoulders) was stable.

Spine side flexion (SF) – the aim of this parameter is to detect a movement compensation by flexing the spine in the coronal plane. To define spine side flexion in every time frame, two vectors were defined: $\overrightarrow{TC_{xz}}$ – vector led form projection of C7 on XZ plane to projection Th12 on XZ plane, $\overrightarrow{TS_{xz}}$ – vector led form projection of Th12 on XZ plane to projection of Sacrum on XZ plane. The angle between $\overrightarrow{TC_{xz}}$ and $\overrightarrow{TS_{xz}}$ vectors (ζ) was measured as shown in the Figure 4.

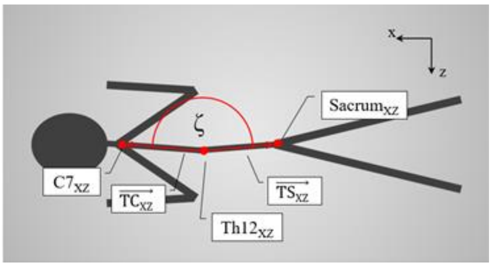


Figure 4. Vectors defined for spine sight flexion

According to equation (5) value of this parameter is defined as deviation of ζ_i (calculated angle) from ζ_{ref} (reference angle) in every time frame of exercise repetition. The reference angle was the angle determined for the starting position. The smaller the change in value of angle is, the less compensation in the motion pattern was observed.

$$SF = \sqrt{\frac{\sum_{i=1}^{m}(\zeta_i - \zeta_{ref})^2}{m}}, \quad (5)$$

where m is the number of the time frames for one exercise repetition, i is the number of the frame, ζ_i is a value of the calculated angle in ith time frame, ζ_{ref} is the value of the reference angle.

Maximum extension degree in elbow joint (ε) – characterizes the range of movement in the elbow joints during torso lifting (forearm extension). In this parameter, the angle between two vectors was evaluated, as shown in the Figure 5. This angle was calculated in every time frame for one exercise repetition, as the angle between two vectors: $\overrightarrow{LS_{XY}}$ – vector led from projection of LS on XY plane to projection of SPR on XY plane, $\overrightarrow{LA_{XY}}$– vector led from projection of LEH on XY plane to projection of AS on XY plane. The maximum value of angle ε was determined separately for the right and left limb and then compared to values of this parameter in other trials. ε indicates whether the test was performed in full available range of motion. Based on value of this parameter it is possible to exclude uncompleted trial from further assessment.

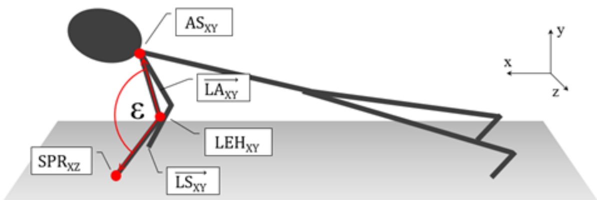


Figure 5. Vectors defined for eextension degree in elbow joint

4. Results

In our study, some parameters described in the previous section were analyzed for trunk stability push-up.

Table 1 shows means and standard deviations of the UTM during uniform lifting and lowering the torso for selected football players obtained from 3 repetitions of the exercise related to the trunk stability push-up. Comparing the results presented in this table, one can notice that the values of the UTM are quite different between the players even if their performances were scored at the same level. However, the mean values of the UTM are rather greater if the exercise was scored lower by the physiotherapist. It means that if the athlete try to perform the exercise fast, then the results are not so good. Furthermore, for lower values of scores the standard deviation of the UTM is greater, except the case of lifting for the performances scored 2 points.

Table 1. Means and standard deviations of the UTM parameter during uniform lifting and uniform lowering the torso for selected female football players

Score	Mean values of the UTM during lifting [deg/s]	Standard deviation of the UTM during lifting [deg/s]	Mean values of the UTM during lowering [deg/s]	Standard deviation of the UTM during lowering [deg/s]
3	1.6780	0.4576	1.9631	0.1773
	2.4432	0.4381	2.7699	0.2516
2	1.5536	0.0439	1.3992	0.5737
	3.6322	0.0590	2.5870	0.6516
1	3.9375	0.9081	3.4529	1.3192
	5.8096	0.6617	4.7059	1.0244

The considered parameters of the trunk stability push-up exercise for a female football player, who performed the exercise scored 2 points, are presented in Table 2. The values from the best repetition, taking into account mean of selected parameter, are marked in green. For all parameters, the lower values are better.

In Table 3 the considered parameters of the trunk stability push-up exercise are presented for a female football player, who performed the exercise scored 3 points. In the same way as previously, the values marked in green denote the values from the best repetition taking into account mean of the selected parameter. Comparing Tables 2 and 3, one can notice that the mean values of the parameters defined in this study are lower for the athlete scored 3 points.

Table 2. Values of the parameters for a female football player, who performed the exercise scored 2 points

Repetition number	1	2	3
UTM – lifting	3.5490	**3.6692**	3.6785
UTM – lowering	2.1967	**2.0592**	3.5050
Mean values	2.8729	2.8642	3.5918
SF – lifting	1.3658	1.9453	**0.7979**
SF – lowering	1.0642	0.8262	**0.7441**
Mean values	1.2150	1.3858	0.7710
ID/FD – beginning of the lifting phase	1.6368	-1.4237	**-1.7524**
ID/FD – beginning of the lowering phase	-6.8462	-6.3668	**-3.9635**
ID/FD – end of the lifting phase	-6.2996	-9.5843	**-5.0655**
ID/FD – end of the lowering phase	-2.8674	0.0617	**-2.3238**
Mean of the absolute values	4.4125	4.3591	3.2761

Table 3. Values of the parameters for a female football player, who performed the exercise scored 3 points

Repetition number	1	2	3
UTM – lifting	2.3034	**1.2214**	1.5091
UTM – lowering	1.7613	**2.1928**	1.9352
Mean values	2.0324	1.7071	1.7223
SF – lifting	**0.5474**	2.1394	0.9088
SF – lowering	**1.4832**	1.8070	1.1361
Mean values	1.0153	1.9732	1.0225
ID/FD – beginning of the lifting phase	**0.5773**	-0.0139	5.1028
ID/FD – beginning of the lowering phase	**-0.4300**	-1.2033	0.3617
ID/FD – end of the lifting phase	**-0.3264**	-1.1612	1.3111
ID/FD – end of the lowering phase	**2.6115**	3.8012	3.7566
Mean of the absolute values	0.9863	1.5451	2.6330

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5. Conclusions

Observation of the physiotherapist, who carries out the FMS test in a standard way, consists of two parts: scoring (0-3) and eventually verbal description of the quality of the performed exercise. Recording of these observations may provide information on dysfunctions that influenced the obtained assessment. However, a verbal description may be difficult to analyze during planning of the further training, rehabilitation or monitoring of progress. The description can be incomprehensible and difficult to use if the physiotherapist has a big group of athletes to test or if the data from test are scored by different physiotherapist.

Furthermore, in the standard FMS test, the difference between the numbers of observed abnormalities by different physiotherapists for the same athlete is possible. The score based on the calculated parameters provides the same set of original data for each single test.

In addition, getting the highest score (3) does not always mean that you have complete the exercise without any mistakes. Performing of some measurements for each test, regardless of the score given by the physiotherapist, allows the observation of any incorrect patterns even for athletes scored 3 points. The use of the motion capture system during the FMS test performing allows to give information contained in the verbal description of the physiotherapist using numbers. It makes easier comparing of the obtained results.

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