Iran J Public Health, Vol. 52, No.5, May 2023, pp.969-977

Original Article

Evaluation of the Accuracy of the Postural Stability Measurement with the Y-Balance Test Based on the Levels of the Biomechanical Parameters of 14-Year-Old Girls

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(Received 16 Jan 2021; accepted 12 Mar 2022)

Abstract

Background: Dynamic balance monitoring involves the assessment of the muscular control during changes of the centre of gravity location in space above the supporting plane. We aimed to determine the structure of the Y-Balance Test and its accuracy based on measurements of strength and resistance to fatigue of muscles acting on the knee joint under static conditions, as well as joint motion ranges and static balance in girls aged 14 years.

Methods: The study included 40 girls aged 14, who attended Gymnasium No. 2 in Cracow (Poland). The research was conducted in October 2020. Postural stability was examined with the use of the YBT. The measurements of muscle strength and knee joint extensor and flexor resistance to fatigue during an isometric contraction were performed in a standard position on the test bench. The measurements of lower extremity joint range of motion were performed in accordance with the SFTR methodology. Static balance was assessed with the use of the modified FBT.

Results: The factor structure obtained for both lower extremities has satisfactorily explained the common variance (about 70%) and showed slight differences between the left and right extremities.

Conclusion: The factor structure in the group of examined girls suggests a highly hybrid nature of the Y-Balance Test with a wide spectrum of biomechanical variables that have little influence on the measurement results.

Keywords: Biomechanics; Motor control; Postural stability; Structure test

Introduction

The issue of lower extremity injury prevention in young athletes has been the third most commonly studied subject in the field of physiotherapy during the last 15 years. To do this, some tests have been created during the recent years, the purpose of which is to determine functionally the risk of injury as well as motor predispositions in athletes (1).

The researchers agree that there are significant relationships between chronic lower extremity joint dysfunctions and postural stability (2,3). In the year 2000, McGuine et al. were the first to

study postural stability (4). Since then, many tests have been developed to assess postural stability under both static and dynamic conditions. In the studies of athletes, dynamic tests are preferred, i.e. the Star Excursion Balance Test (SEBT) and the Y-Balance Test (YBT) (1).
Docherty et al. believe that functional tests that reproduce natural training conditions or normal life scenarios may be more sensitive in abnormality detection than the static ones (5).
All functional tests typically have a hybrid structure, i.e. they test several areas of human motor function at the same time. Therefore, it is crucial for the diagnosis to use a highly accurate test. In the literature published so far, the accuracy of the Y-Balance Test has usually been assessed in terms of the ability of the test to reflect motor system functional status of the subject (6-8). One of the research directions is to verify the accuracy of the Y-Balance Test in measuring of the levels of basic biomechanical variables and their effect on test results (9).
We aimed to determine the structure of the Y-Balance Test and its accuracy based on measurements of strength and resistance to fatigue of muscles acting on the knee joint under static conditions, joint movement ranges and balance in girls aged 14.

Materials and Methods

Participants

The study involved 40 girls aged 14 who attended Gymnasium No. 2 in Cracow (Poland). The research was conducted in October 2020. The research project gained the approval of the Bioethics Committee of the Regional Medical Chamber in Cracow (Opinion No. 175/KBL/OIL/2020 of July 14, 2020). The parents of the examined girls gave their written consent to the research.
Table 1 presents the characteristics of the studied girls. Height, weight and BMI did not have a normal distribution, but the dispersion of the V results was small and ranged from 4%-20%. At the beginning, the height and weight of the subjects were measured and the laterality was diagnosed with the 'step forward' test (10). Only right-footed girls continued their participation in the further part of the study. The measurement of body height was done with 1 cm accuracy. Body weight was measured with an electronic scale with a 0.1kg accuracy.

Table 1: Characteristics of the study subjects

Variables	**Girls** Average ± SD
Age (yr)	13.90±0.30
Height (m)	1.59±0.06
Weight (kg)	54.30±13.60
BMI (kg/m^2)	21.20±4.60

Instrumentation

Examination of Dynamic Postural Stability

Postural stability was examined with the use of the Y-Balance Kit (6-8). During the analysis of the results, the highest achieved reach result in each direction during unilateral stance was corrected for the length of the stance extremity, according to the following formula:

$$MAXD\ (\%) = [EL / LL] \times 100 \quad [1]$$

Composite YBT score was also calculated for each subject, using the following formula (2):

$$YBT\text{-}CS\ (\%) = [(AN+PM+PL)/(LL \times 3)] \times 100 \quad [2]$$

MAXD (%) = the maximum reach distance in one direction in %, EL = distance of reach in one direction, LL = relative length of the extremity, YBT-CS (%) = YBT composite reach score, AN = anterior reach, PM = posteromedial reach, PL = posterolateral reach.

Measurements of Muscle Group Strength and Muscle Resistance to Fatigue

The measurements of muscle strength and knee joint extensor and flexor resistance to fatigue in an isometric contraction were performed in a standard seated position on the test bench, with the use of strain gauges. The accuracy of dynamometric measurements was determined by the accuracy level of the force sensor (error at the level of 0.5%). The force arm "d" was measured as the distance between the biomechanical axis of rotation of the knee joint and the centre of the dynamometer band in the position shown in Fig. 1. The force arm was measured with an accuracy of 0.01 m.

Based on the recorded maximum force, the maximum [3] and relative [4] muscle torques for knee joint flexors and extensors were calculated (Mmax [Nm]):

$$Mmax = Fmax \cdot d \qquad [3]$$

With: Fmax – maximum force of the tested muscles during an isometric contraction [N], d – external force arm [m]

The relative muscle torque (RT [$Nmkg^{-1}$]) has been calculated according to the following relationship:

$$RT = Mmax \cdot m^{-1} \qquad [4]$$

With: m — body mass [kg]

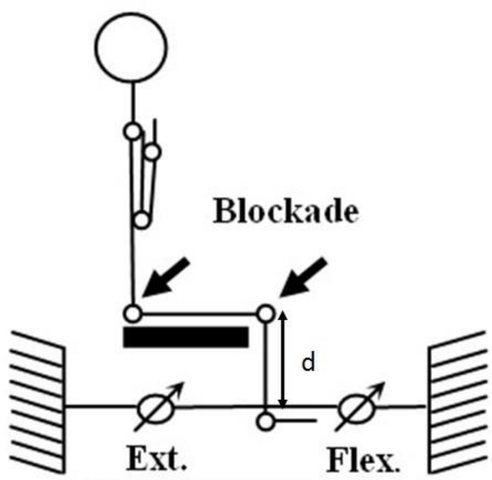

Fig. 1: Standard position for measurements of the maximum muscle torques and knee joint flexors' and extensors' resistance to fatigue

The same standard position was used to determine the muscle resistance to fatigue during the maximum isometric contraction. The task of the subject was to achieve the maximum level of force and to maintain it for 15 sec. The results of the measurements were used to determine the strength regression index CRF [N/s] [5]:

$$CRF = (Fmax - Fmin) \cdot t^{-1} \qquad [5]$$

Fmax [N] – the maximum muscle strength recorded during the isometric contraction [N], Fmin – the minimum muscle strength recorded during the isometric contraction

[N], t – the effective contraction time of a muscle group [s], where the decrease of muscle strength can be approximated to a straight line.

Measurements of the Range of Motion in the Lower Extremity Joints

A measurement of the range of motion of the lower extremity joints was performed according to the SFTR (11). Extension, flexion, abduction, adduction and external and internal rotation were measured in the hip joint, flexion – in the knee joint, and dorsal and plantar flexion – in the ankle joint. Measurements were taken with an accuracy of up to 1°.

Static Balance Test

The examination of static balance was performed with the use of the single leg balance test – 'Flamingo Balance Test' (12). The time was measured with the accuracy of 1 second.

Statistical Method

At first, the nature of the value distributions of the studied variables was determined, using the Shapiro-Wilk W test, and the coefficient of variation V% was calculated. Then, the variables for factor analysis were pre-selected. Factor analysis was performed using the principal component method based on a correlation matrix. The analysis included factor rotation according to the Varimax method to maximize the variance of the baseline variables.

Creation of Representative Variables

The number of variables obtained from the measurements and calculations appeared to be redundant. The interpretation of the factor analysis was also disturbed by too many variables describing the range of joint motion in particular planes. For this reason, representative cumulative ranges of motion in hip, knee and ankle joints, and the sum of motion of all studied joints were selected for analysis.
The following variables were obtained for each lower extremity as a result of mathematical operations:
FBT [s] - Flamingo Balance Test,
Y-ANT [%] - the anterior component of the Y-Balance Test,
Y-POST-MED [%] - the posteromedial component of the Y-Balance Test,
Y-POST-LAT [%] - the posterolateral component of theY-Balance Test,
Y-CS [%] - the global result of the Y-Balance Test,
ROM_HKA [°] - the cumulative range of motion in the hip joint (ROM_H), knee joint (ROM_K) and ankle joint (ROM_A),
ROM_H [°] - the cumulative range of motion in the hip joint (extension, flexion, abduction, adduction, and external and internal rotation),
ROM_K [°] - the range of knee joint flexion,
ROM_A [°] - the cumulative range of motion in the ankle joint (dorsal and plantar flexion),
CRF Ext [N/s] - knee joint extensor strength regression index in the fatigue resistance test,
CRF Flex [N/s] - knee joint flexor strength regression index in the fatigue resistance test,
RT Ext [Nm/kg] - knee joint extensor relative torque,
RT Flex [Nm/kg] - knee joint flexor relative torque,
RT Ext/Rt Flex - knee joint extensor to flexor relative torque ratio.

Results

As a result of the analysis, a normal distribution of the examined variables was found at the level of $P<0.05$, with the exception of CRF Ext L, CRF Ext R, CRF Flex L and FBT L. The value of their coefficient of variation was high and ranged from 53%-98%, which indicates a significant dispersion of individual results. The coefficient of variation for CRF Flex R was 31%, but the variable was normally distributed. The coefficient of variation for all other variables was within 5%-22%. E-value of their coefficient of variation was hiranged from 53-98%, which Table 2 shows the values of the factor loadings of the selected left and right lower limb variables in relation to the results of the YBT. The isolated factor structure for the left lower limb YBT result variables in the girls included five major independent factors characterising the structure of the variables analysed (Table 3). They explained 69% of the common variability in total.

Table 2: Factor structure of the results for the left and right lower extremities in the studied group of girls, isolated with the use of the principal component method (Varimax rotation)

Variables	*Factor 1*		*Factor 2*		*Factor 3*		*Factor 4*		*Factor 5*	
	LLE	**RLE**	**LLE**	**RLE**	**LLE**	**RLE**	**LLE**	**RLE**	**LLE**	**RLE**
FBT_L [s]	0.12	0.42	0.14	0.38	0.23	-0.03	0.50	0.32	-0.27	-0.04
Y-ANT_L [%]	0.15	0.76	0.02	0.15	0.78	0.28	-0.15	-0.23	0.18	-0.01
Y-POST-MED_L [%]	0.05	0.81	0.00	-0.11	0.86	0.10	0.10	0.21	0.00	0.09
Y-POST-LAT_L [%]	0.19	0.87	0.23	-0.07	0.77	0.04	0.08	0.01	-0.04	0.01
Y-CS_L [%]	0.15	0.97	0.12	-0.04	0.95	0.14	0.04	0.03	0.03	0.04
ROM_HKA_L [°]	0.91	0.11	0.00	0.32	0.15	0.85	0.05	0.05	0.14	0.03
ROM_H_L [°]	0.81	-0.01	0.09	0.35	0.13	0.73	0.05	-0.09	-0.23	-0.35
ROM_K_L [°]	0.55	0.14	-0.01	0.08	0.04	0.62	0.35	0.01	0.30	0.39
ROM_A_L [°]	0.36	0.17	-0.16	0.09	0.10	0.36	-0.21	0.26	0.63	0.42
ROM_HKA_R [°]	0.83	0.23	0.30	0.03	0.21	0.89	0.02	0.04	0.18	0.02
ROM_H_R [°]	0.78	0.17	0.35	0.10	0.06	0.76	-0.10	0.07	-0.24	-0.33
ROM_K_R [°]	0.52	0.04	0.06	-0.02	0.25	0.62	0.13	0.21	0.41	0.32
ROM_A_R [°]	0.28	0.21	0.06	-0.11	0.24	0.38	0.13	-0.18	0.58	0.53
CRF Ext_L [N/s]	-0.26	0.29	-0.13	0.25	0.03	-0.28	0.19	0.07	0.57	-0.26
RT Ext_L [Nm/kg]	0.27	-0.02	0.77	0.90	-0.02	0.03	-0.34	-0.34	0.04	-0.03
CRF Flex_L [N/s]	-0.38	-0.35	0.47	0.26	0.00	-0.27	0.19	0.05	0.50	0.52
RT Flex_L [Nm/kg]	0.20	-0.16	0.87	0.84	0.24	0.14	0.21	0.36	0.02	0.01
RT Ext_L/Flex_L	-0.02	0.13	-0.23	0.19	-0.28	-0.08	-0.73	-0.86	-0.04	-0.12
CRF Ext_R [N/s]	-0.28	0.17	0.16	-0.14	0.35	-0.19	-0.09	0.09	-0.10	0.67
RT Ext_R [Nm/kg]	0.03	-0.13	0.89	0.75	0.10	0.27	-0.32	-0.38	-0.04	0.07
CRF Flex_R [N/s]	-0.29	0.08	0.31	0.47	-0.43	-0.34	0.03	0.21	0.47	0.52
RT Flex_R [Nm/kg]	0.12	0.10	0.85	0.88	-0.01	0.23	0.37	0.22	-0.03	-0.02
RT Ext_R/Flex_R	-0.04	-0.24	0.16	-0.26	0.11	-0.07	-0.86	-0.79	-0.08	0.03
Share in the variance [%]	0.18	0.16	0.16	0.16	0.16	0.19	0.10	0.10	0.09	0.09

LLE - the left lower extremity, RLE - the right lower extremity, L – left, R – right, Ext – extention, Flex – flexion, A – ankle, K – knee, H – hip

Factor 1 LLE, explaining 18% of the common variance of the variables, loaded the variables that characterized motion ranges in lower extremity joints. The values of the factor loadings of the variables were between r=0.52 and r=0.91. The cumulative motion range in the left and right limbs (ROM_HKA_L, ROM_HKA_R) showed the highest correlation with the factor.

Factor 2 LLE that explains 16% of the common variance of the variables loaded the variables that characterized relative knee joint flexor and extensor torques. The correlations with the factor were between r=0.85 for the right knee joint flexor relative torque variable (Mw Flex_R) and r=0.89 for the right knee joint extensor relative torque variable (RT Ext_R).

Table 3: The left and right lower extremity factors in the group of examined girls isolated by the principal component method (Varimax rotation)

Isolated Factors	*Structure of factors in the group of examined girls*	
	LLE	**RLE**
Factor 1	motion ranges in the lower extremity joints	the result of the YBT test
Factor 2	knee joint flexor and extensor relative torques	the relative knee joint extensor torque
Factor 3	the result of the YBT test	movement ranges in the lower extremity joints
Factor 4	ratio of the relative knee joint extensor to flexor torques	ratio of the relative knee joint extensor to flexor torques
Factor 5	ankle joint motion range	The regression index of the knee extensor muscle strength

Factor 3 LLE explaining 16% of the common variance of the variables contained the highest factor loadings of the YBT test results. Additionally, regression of right knee joint extensor (r=0.35) and flexor (r=-0.43) muscle strength (CRF Ext_R, CRF Flex_R) can be distinguished in the structure of the factor (CRF Ext_R, CRF Flex_R).

Factor 4 LLE explained 10% of the common variance and was mostly loaded with the indices of *the extensor to flexor relative torque proportion* (RT Ext/Flex) of the left (r=-0.73) and right (r=-0.86) knee joints. This factor also contains a variable that characterizes the result of the Flamingo Balance Test (FBT_L) (r=0.50).

Factor 5 LLE explaining 9% of the common variance loaded the variables of *range of motion in ankle joints of both lower limbs* (ROM_A) and indices of regression of right and left knee joint extensor and flexor strength (CRF Ext_L, CRF Flex_L).

The isolated factor structure for the right lower limb YBT result variables in the girls' also included five major independent factors characterising the structure of the variables analysed (Table 3). They explained 70% of the common variability in total.

Factor 1 RLE explaining 16% of the common variance of the variables loaded the variables characterizing *the YBT results*. The result of the Flamingo Balance Test (FBT_R) (r=0.42) was the parameter with the highest correlation with factor 1 RLE.

Factor 2 RLE explained 16% of the common variance of the variables and loaded the variables of *relative torques of the left and right lower limb extensors* (RT_Ext) and *flexors* (RT_Flex). Higher values of correlation were shown for the right extremity variables, equal to r=0.90 for extensors and r=0.84 for flexors.

Factor 3 RLE explaining 19% the common variance of the variables, loaded the variable of range of motion in lower extremity joints: cumulative mobility in the left and right extremity joints (ROM_HKA), cumulative mobility in the left and right hip joints (ROM_H), and range of motion for knee joint flexion (ROM_K).

Factor 4 RLE explaining 10% of the common variance of the variables was named *the index of extensor to flexor relative torque proportion* of the left (r=-0.79) and right (r=-0.86) knee joints (RT Ext/Flex). Factor loadings of the YBT test results were low and were r=-0.23 for the forward direction (Y-ANT_R) and r = 0.21 for the posteromedial direction (Y-POST-MED_R).

Factor 5 RLE explained 9% of the variance of the variables and loaded the variables of the YBT to the least extent. However, it loaded significantly the variables characterizing *the regression index of knee joint extensor* (CRF Ext) *and flexors* (CRF Flex) strength as well as the range of motion of the left limb ankle joints (ROM_A_L).

Discussion

On the basis of the result obtained in YBT, it is possible to assess dynamic postural stability, which is the resultant of the range of mobility in the joints, flexibility and muscle strength as well as neuromuscular control (13,14). The factor structure obtained for both lower extremities among the girls has satisfactorily explained the common variance (approx. 70%) (Table 3).

The strongest relationships were shown for YBT results in the right extremity with the Flamingo Balance Test (FBT_L) and with the knee joint flexor strength regression index (CRF Flex_L). Slightly lower values of factor loadings (above r=0.2) were recorded for the extensor strength regression index (CRF Ext_L), the range of motion in the joints (ROM_HKA_R, ROM_A_R) and the ratio of relative extensor to flexor torques (RT Ext_R/Flex_R).

The analogous YBT factor in the left extremity loaded most strongly the variables of knee joint flexor and extensor strength regression index (CRF Flex_R, CRF EXT_R), and slightly less strongly through the 'Flamingo Balance Test' (FBT_L), motion ranges in the joints of the lower extremities (ROM_HKA_R, ROM_K_R, ROM_A_R), and knee joint extensor to flexor relative torque ratio (RT Ext_L/Flex_L).

Numerous and relatively low values of correlation between biomechanical variables and the results of the YBT provide evidence of high hybridity of this tests in the group of [examined] girls without any predominant relationship with one group of biomechanical variables. This observation is also confirmed by strong autonomous factors selected by factor analysis for both lower extremities, presented in Table 3.

A slightly different factor structure in the group of the examined girls for either limb and differences in the factor structure as compared to the group of boys presented by authors in their earlier work may be a result of intra-group variability between the subjects (13). 14-year-old boys formed a more homogeneous group in terms of physical development, as they enter puberty at a later age (9, 15).

Considering the issues addressed in this work, the reports of Lee et al. seem interesting. The YBT effectiveness was found to be affected by the lower limb muscle strength (16). No strong relation of YBT results with muscle strength was found in the studied group of girls. There is a relationship between knee joint extensor muscle strength and the result of the postural stability test, which was not directly confirmed by our results (17).

Booysen et al. considered the eccentric strength of the thigh muscles parameter a component of the YBT (18). As in our study, they did not observe any direct relationships between the eccentric strength of the knee joint flexors and the YBT results. Performance of the YBT generates a co-contraction of the antagonistic knee joint muscles, especially when approaching the maximum of leg extension. Thus, the active work of knee joint flexors can, on the one hand, prevent achievement of better YBT results, but on the other hand, by improving joint stability, have a positive impact on the result. The results obtained in this work are in opposition to the results presented to date (19). The involvement of anti-gravity muscles (extensors) is much bigger than that of flexors in the YBT. This fact should explain isolation of the relative torques of knee joint extensors in the same factor as YBT results.

In the examination of the accuracy of the YBT, the measurement of the rate of muscle strength loss in anaerobic conditions was also used, represented by the CRF variable. The presence of this component proved to have a limited effect on the YBT result.

Other authors clearly indicate the effect of fatigue on the test result. Youm et al. have shown as high as 95% effect of fatigue of the lower extremity muscles (caused by standing on tiptoes repeated several times) on the postural stability during one-leg stance (20). Ebrahimi et al. also suggest increased posture instability (and thus reduced values of the YBT) after the fatigue test, as compared to the pre-test result (15). Salo et al. have shown, however, regressions in the YBT result for the lower limb during the post-training period in people who practised recreational strength training (21). CRF is an indicator that describes the rate of strength decrease in the trial of 15-second isometric contraction. With regards to what has just been presented above, it represents a difference form of anaerobic fatigue.

Recognition of the motor skill areas that were not measured by the YBT in the examined group of 14-year-old girls is also an indubitable value of our observations. These include all those variables that have shown autonomy with respect to the YBT results. Similar conclusions were drawn from a study that showed there is no correlation between YBT results and the stability index measured with the Biodex Balance System (22).

For this reason, it seems necessary to determine the accuracy of the tests used to assess postural stability. In spite of a large number of publications concerning studies in adults, the reports on children and adolescents may be of particular interest. This is confirmed by the discrepancy between the results obtained in girls and boys aged 14, indicating that the gender-specific motor skill level in different areas led to isolation of a different factor structure in both groups (13). It therefore seems necessary to check the accuracy of the YBT for both sexes in other age groups, in order to determine the suitability of this test at different levels of somatic development of the subjects.

Conclusion

Factor structure in the group of the examined girls suggests a highly hybrid nature of the YBT with a wide spectrum of biomechanical variables that have little influence on the measurement results. The isolated factor structure in the group of adolescent girls depends on their motor skill level in terms of joint mobility, strength capacity and the rate of muscle strength decrease and that there is a difference between girls and boys of the same age. The isolated clear factor structure in the group of girls was identical for both lower extremities in terms of four factors. As far as the fifth factor, however, a difference occurred between both extremities.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgements

We received no financial source for the study.

Conflict of interest

The authors declare that there is no conflict of interest.

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