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Composite Score of Readiness (CSR) as a Data Reduction Technique for Monitoring the RTS Process in Footballers following ACL Reconstruction

Łukasz Oleksy [1,2], Anna Mika [3,*], Renata Kielnar [4], Miłosz Szczudło [5], Henryk Racheniuk [6], Olga Adamska [7], Marian Rzepko [8], Aleksandra Królikowska [9], Paweł Reichert [10], Robert Prill [11] and Artur Stolarczyk [7]

1 Faculty of Health Sciences, Department of Physiotherapy, Jagiellonian University Medical College Krakow, 31-008 Krakow, Poland
2 Oleksy Medical & Sport Sciences, 37-100 Łańcut, Poland
3 Institute of Clinical Rehabilitation, University of Physical Education in Kraków, 31-571 Kraków, Poland
4 Institute of Health Sciences, Medical College of Rzeszów University, 35-315 Rzeszów, Poland
5 Center of Sport and Recreation, University of Rzeszow, 35-315 Rzeszów, Poland
6 Institute of Physiotherapy, Faculty of Physical Education and Physiotherapy, Opole University of Technology, 46-020 Opole, Poland
7 Department of Orthopaedics and Rehabilitation, Medical Faculty, Medical University of Warsaw, 02-091 Warszawa, Poland
8 Institute of Physical Culture Sciences, Rzeszów University, 35-310 Rzeszów, Poland
9 Ergonomics and Biomedical Monitoring Laboratory, Department of Physiotherapy, Faculty of Health Sciences, Wrocław Medical University, 50-367 Wrocław, Poland
10 Department of Trauma Surgery, Clinical Department of Trauma and Hand Surgery, Faculty of Medicine, Wrocław Medical University, 50-367 Wrocław, Poland
11 Center of Orthopaedics and Traumatology, University of Brandenburg an der Havel Theodor Fontane, 14770 Brandenburg, Germany
* Correspondence: anna.mika@awf.krakow.pl

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Abstract: In recent years, many studies on the safe return to sport (RTS) have been published, but there are still no clear and validated guidelines. After ACL reconstruction between limbs, asymmetry of muscle strength affects knee mechanics during walking and running, and asymmetrical joint kinematics and kinetics are considered as a strong risk factor of musculoskeletal injury. Therefore, proper diagnosis of any motor deficits remaining after ACL reconstruction seems particularly important. The aim of this study was to analyze how many tests should be included in the RTS test battery and which of them are most indicative for functional deficits related to anterior cruciate ligament (ACL) reconstruction. Sixty-five male football players (age 18–25 years) were divided into three groups: ACL group—after ACL rupture and reconstruction, mild injury group—post mild lower limb injuries, and the control group—without injuries. They performed five tests: Functional Movement Screen, Tuck Jump Assessment, Y-balance Test, Hop Test for Distance, and Isokinetic Test. The Composite Score of Readiness (CSR) index was calculated and expressed as the sum of z-scores. The multiple regression model for all tests was calculated, and then redundant variables were excluded. We observed that all tests significantly influenced the final CSR index. The Y-balance Test, Tuck Jump Assessment, and Isokinetic Test for knee flexion influenced the final CSR index the most, which means that these tests are greatly indicative of functional deficits related to ACL reconstruction. The strength of the extensor (quadriceps) muscle and the quadriceps/hamstring ratio appeared to be non-sensitive for testing functional deficits related to ACL reconstruction. If the test battery includes 4–5 tests, it better differentiates the athletes following ACL reconstruction from those after mild injuries, even if they all were cleared to play.

Keywords: anterior cruciate ligament (ACL); composite score of readiness (CSR); injury prevention; rehabilitation; football; soccer

1. Introduction

Anterior cruciate ligament (ACL) injuries are very common in landing- and pivoting-type sports [1,2]. However, ACL reconstruction is a standard in restoring knee stability before return to sport (RTS) [2]. The number of athletes who successfully return to pre-injury level is low [2–5]. Nonetheless, it has been reported that generally passing RTS criteria reduced the risk of subsequent graft rupture by 60% [1,6], whereas the rate of ACL re-injury in athletes under the age of 20 was between 23% and 40% [1,6–8]. It has been underlined by some authors that current RTS criteria are moderately effective in reducing the risk of subsequent ACL injury among athletes [9,10]. Beischer et al. [11] showed that 8 months after ACL reconstruction, only 29% of the evaluated athletes achieved a limb symmetry index of above 90% for five muscle function tests during RTS testing. It was reported that the overall pattern is that the involved leg is weaker than the uninvolved leg, which itself is weaker than in matched healthy controls [12].

The risk of graft rupture after ACL reconstruction remains high and most frequently tends to occur within the first 6 months to 2 years following RTS [9,13]. In the literature, it has been indicated that many athletes, even 2 years after ACL reconstruction, demonstrate characteristic deficits in neuromuscular control, strength, landing kinematics, proprioception, psychological readiness, and perception of knee function [14–19]. Moreover, Paterno et al. [20] reported that predictors of ACL re-injury with 92% sensitivity and 88% specificity are a combination of neuromuscular and biomechanical factors, including transverse plane hip moments, frontal plane knee angles, sagittal plane knee moments, and deficits in postural stability. These findings are very important because they demonstrated that passing the RTS does not provide protection against graft rupture, and residual or undetected deficits in neuromuscular control are highly related to a second ACL injury [9–11,14,15]. What is more, such graft rupture may lead to an increased risk of early onset regarding knee osteoarthritis [21]. Although many studies on the safe return to sport have been published in recent years, there are still no clear or validated guidelines [1,6]. Therefore, there is a need to verify the effectiveness of RTS tests used today to determine which of them are the most sensitive to detecting ACL-specific deficits, and which due to their non-specificity and low diagnostic efficiency should not be applied in RTS [7,10,12,22]. The reported test batteries differ from each other; however, they are designed to incorporate several domains, including Isokinetic Strength Tests, Hop Tests, jump–landing task, and measures of quality of movement, as well as self-reported information [1,6,7,14,19,22]. In recent studies, it has been reported that concentric isokinetic quadriceps strength and hop testing, expressed as limb symmetry indices (LSI), were most commonly used for RTS assessment of an athlete's readiness to return to unrestricted sport after ACL reconstruction [22,23]. However, the most important issue in determining the test battery seems whether RTS is to a pivoting or non-pivoting sport, contact or non-contact sport, and the same or different pre-injury sport and competitive level [12].

Another unresolved question is that of how many individual tests should be performed in comprehensive RTS assessment. In studies, the inclusion of up to 15–20 different RTS tests has been reported [6,24], but the validity of many of them is unknown [25]. It has certainly been recommended that RTS testing after ACL reconstruction should include many tests, but it is unclear which would be the most appropriate.

Due to the fact that the coaching staff require readable and easy-to-use indications of an athlete's readiness to play [26], the previously reported single-score injury risk index called the Composite Score of Readiness (CSR) may provide such information [27]. Thus, there is a need for unification of test interpretation and determining which tests are the most indicative of deficits after ACL reconstruction. Because musculoskeletal alterations are present not only after serious injury such as ACL rupture, but also following mild injuries, it was suggested that each trauma has some consequences on the motor system [28]. The amount of these deficits is not clear, and also we do not know if passing the RTS after ACL reconstruction guarantees that they are minimal or comparable to those mild injuries to the lower limbs common in sport [28].

It was reported that after ACL reconstruction between limbs asymmetry of muscle strength affects knee mechanics during walking and running [29]. In addition, kinematic and kinetic asymmetries between limbs were noted [9]. It was reported that due to the tensegrity model all asymmetrical tensions transmitted throughout musculofascial structures may lead to micro trauma, even in distant parts of the body [30,31]. Therefore, asymmetrical joint kinematics and kinetics were linked with changes in muscle and tendon length [32], and were considered as a strong risk factor of musculoskeletal injury [32,33]. Therefore, proper diagnosis of any motor deficits remaining after ACL reconstruction seems particularly important.

Despite the development of RTS guidelines over recent years, there is a lack of scientific consensus on the RTS criteria used to release athletes to unrestricted sport activity after ACL reconstruction [1,34]. Therefore, the aim of this study was to analyze how many tests should be included in the RTS test battery and which tests are most indicative for functional deficits related to ACL reconstruction.

The key points presented in this paper are the following:

1. The number of athletes who successfully return to pre-injury level of sport after ACL reconstruction is relatively low.
2. Studies have reported that passing the RTS does not provide protection against graft rupture, and residual or undetected deficits in neuromuscular control are highly related to a second ACL injury.
3. There are still no clear or validated guidelines about RTS testing after ACL reconstruction.
4. This study analyzed how many tests should be included in the RTS test battery and which tests are most indicative for functional deficits related to ACL reconstruction.

2. Materials and Methods

2.1. Participants

In this study, sixty-five male football players recruited from regional teams were included (Table 1).

Table 1. Subjects' characteristics.

	Group 1	Group 2	Group 3
Number of subjects (n)	24	21	20
Height (cm)	175 ± 4	177 ± 6	178 ± 6
Weight (kg)	77.3 ± 7.6	74.3 ± 9.1	75.8 ± 8.8
Age	22.7 ± 3.6	20.5 ± 3.7	23.1 ± 2.8

No significant differences were found for any of the variables.

The participants were divided into 3 groups:

Group 1 (ACL) (n = 24)—after ACL rupture and reconstruction (involved leg—after ACL reconstruction, uninvolved leg—contralateral limb without ACL injury);
Group 2 (MI) (n = 21)—after mild lower limb injury during the previous 2–3 years (involved leg—after mild injury, uninvolved leg—contralateral limb without injury);
Group 3 (C) (n = 20)—controls without injuries (the left limb was the equivalent of the involved limb, and the right limb was the equivalent of the uninvolved limb).

The subjects following ACL reconstruction met the following inclusion criteria: regular football training at a regional team level; first unilateral ACL rupture and reconstruction 2–3 years before the study; passing RTS; and no injuries to the contralateral leg (uninjured leg). The athletes with bilateral ACL or graft rupture and those without ACL reconstruction were excluded. The inclusion criteria for Group 2 were the following: clearance to play after grade 1 or "mild" lower limb muscle injury according to Grassi et al. [35] and no history of any other injuries to the lower or upper limbs and the trunk during the 3 years prior to the study. The inclusion criteria into Group 3 were the lack of any lower or upper limb and trunk injuries in the past.

The study participants were in detail informed about the research protocol. They gave written informed consent to participate in the study. Approval of the Ethical Committee at the Regional Medical Chamber in Kraków was obtained for this study (16/KBL/OIL/2016). All procedures were performed in accordance with the 1964 Declaration of Helsinki and its later amendments.

2.2. Procedures

The athletes were asked not to perform the day before measurements any vigorous training to avoid the effects of cumulative muscular fatigue. All subjects completed 5 tests: Functional Movement Screen (FMS), Tuck Jump Assessment (TJA), Y-balance Test (YBT), Hop for Distance Test (HT), and Isokinetic Test (IT). All tests were performed by experienced staff who were blinded to subject group allocation. Prior to testing, the athletes performed a 5 min warm-up and were familiarized with all measurements. There were 15 min intervals between the tests.

2.2.1. Functional Movement Screen Test (FMS)

The FMS test (Functional Movement Systems Inc., Chatham, VA, USA) was used to evaluate body asymmetry and low-quality movement patterns. It was performed according to the original methodology reported by Cook et al. [36–38]. The composite score of the test was analyzed. The reported reliability of the FMS test was for the inter-rater ICC = 0.87–0.89 and intra-rater ICC = 0.81–0.91 [39,40].

2.2.2. Y-Balance Test (YBT)

The YBT (Move2Perform, Evansville, IN, USA) was performed according to the reported criteria [41,42]. Three reach trials were measured in each direction, first standing on the right leg and then on the left [42]. The composite scores for injured (right) leg and for uninjured (left) leg were analyzed. The intra-rater reliability of the YBT was reported as ICC = 0.85–0.91 and inter-rater ICC = 0.85–0.93 [42,43].

2.2.3. Tuck Jump Assessment (TJA)

TJA was performed in accordance with previously reported protocols [44]. During the jumping effort, each athlete was recorded from the sagittal and frontal plane using the NiNOX 125 camcorder (NiNOX 125, Noraxon USA, Scottsdale, AZ, USA) with the resolution 736/352 and 125 fps frame rate. Technique flaws were assessed on the video and scored according to previously published forms [44]. The composite score of the test was analyzed. The TJA intra-tester mean percentage of exact agreement was reported between 87.2% and 100%, with kappa values of k = 0.86–1.0 [45].

2.2.4. Isokinetic Test (IT)

The measurement was performed using an isokinetic dynamometer (System 4, Biodex Medical Systems, Shirley, NY, USA) in a seated position with the lower limb flexed in the hip joint to 90°, with the knee axis of rotation at the anatomical axis of the joint. The subjects were fastened with a stabilizing strap to prevent trunk movements during measurements. The movable arm of the dynamometer was fixed at 1/3 of the distal end of the tibia. Total range of knee joint motion (ROM) was set from full extension to full flexion. Gravity correction was performed by measuring the torque exerted on the dynamometer resistance adapter by the relaxed, fully extended knee. Concentric Isokinetic Tests were carried out on the quadriceps and hamstrings of both legs. The tests included 10 maximum isokinetic concentric knee join flexions and extensions at each of the 3 angular velocities, 60°/s, 180°/s, and 300°/s, with a 30 s interval for rest between them. The following variables were analyzed separately for the injured (right) and uninjured (left) leg: peak torque/body mass for flexion and extension and hamstring to quadriceps peak torque ratio (H/Q ratio). The result was the mean value of 10 contractions for each angular velocity. As previously reported, the reliability of peak torque was good and ICC ranged between 0.85–0.98 for knee extension and 0.88–0.97 for knee flexion [46,47].

2.2.5. Hop Test for Distance (HT)

The athletes performed a single-leg hop for distance [12,48]. The test was performed bilaterally, starting with the right leg. The objective was to hop as far as possible on one leg with a controlled landing. The maximum distance of the 2 trials was used for analysis. The limb symmetry index was also calculated. For the Hop Test, excellent reliability was reported, ICC = 0.97 [49,50].

2.2.6. Composite Score of Readiness (CSR)

The CSR index was calculated based on the5 performed tests: FMS, TJA, YBT, HT, and IT. The CSR was the sum of z-scores, which represented the number of standard deviations by which the value of a raw score was above or below the mean of the measured variables. A detailed description of the CSR index was presented in a previous work [27]. Due to the fact that z-scores and SD are unitless, the results were summed across all tests. The CRS allows to highlight an athlete's motor deficits in particular tests relative to the control group (without injuries). The interpretation of the CSR is as follows: 0 represents the group average, any value above 0 means that the athlete is better than average, and values below 0 indicate worse performance (higher functional deficits) [27].

Two kinds of CSR indices were calculated:

$CSR_{A\text{-}H}$—for athletes after ACL reconstruction, relative to the group of athletes without injuries;
$CSR_{M\text{-}H}$—for athletes after mild lower limb injuries, relative to the group of athletes without injuries.

2.2.7. Statistical Analysis

STATISTICA 13.0 Pl software was used in this study. The normality was checked with Shapiro–Wilk test. The *t*-test was used to determine the differences between CSR indices. Multiple regression models for all tests were calculated. Partial correlation coefficients (r) and variable tolerance were additionally calculated. Variables were considered as redundant if they had a non-significant beta coefficient (B), a low and non-significant partial correlation coefficient (r), or low tolerance (below 0.1). By eliminating redundant variables, we obtained sufficiently strong indicators showing the strength of the contribution regarding each variable to the formation of the CSR index. Statistical significance was set at the level of $p < 0.05$.

3. Results

3.1. The Values of $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ in Individual Athletes and the Difference between $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ Indices

$CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ calculated from FMS, TJA, YBT, HT, and IT tests indicated that athletes after ACL reconstruction were in a functionally worse state than those following mild injuries (Figures 1A and 2A). More bars with positive values indicated that more athletes had less functional deficits. More bars with negative values mean that evaluated athletes had more functional deficits.

$CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ calculated from four or five tests better differentiated athletes after ACL reconstruction from those after mild injuries, because the difference in the CSR value between the groups was higher (Figure 2B). For $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ calculated from three tests, the difference was weaker, and for $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ calculated from two tests, the difference was low and non-significant (Figure 1B).

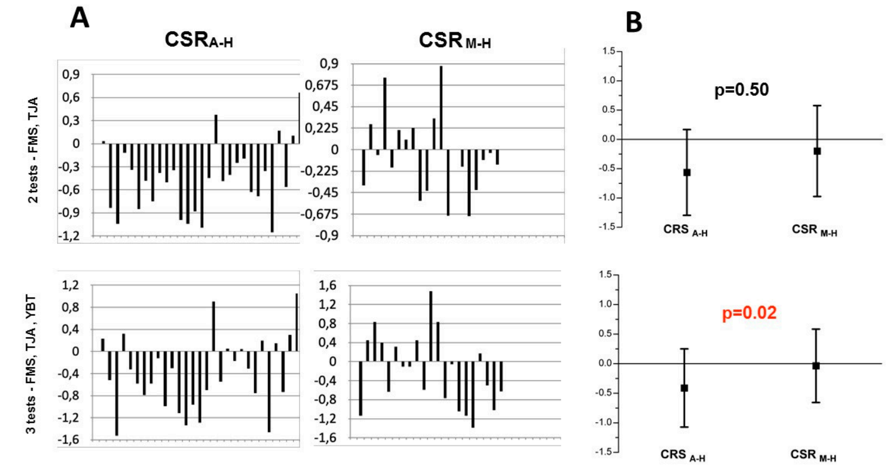

Figure 1. (**A**) Values of $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ in individual athletes from 2 and 3 tests. Zero represents the group average of CSR value; bars with a positive value mean that the particular athlete is better than average; and bars with a negative value mean that the particular athlete is worse than average. (**B**) The difference between $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ indices.

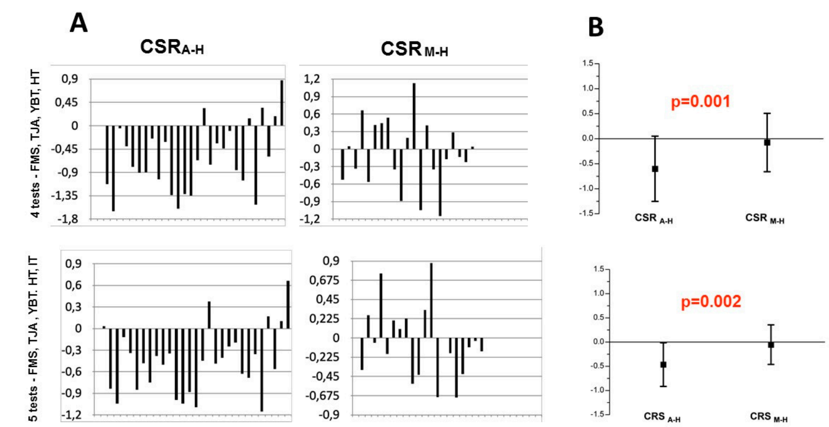

Figure 2. (**A**) Values of $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ in individual athletes from 4 and 5 tests. Zero represents the group average of CSR value; bars with a positive value mean that the particular athlete is better than average; bars with a negative value mean that the particular athlete is worse than average. (**B**) The difference between $CSR_{A\text{-}H}$ and $CSR_{M\text{-}H}$ indices.

3.2. Multiple Regression Model

3.2.1. Multiple Regression Model When All Variables Were Included

By eliminating step by step the redundant variables from the model, we obtained sufficiently significant indicators of the contribution strength to the formation of the CSR index concerning each of the variables (each test).

Redundant variables were non-significant in the model and presented low tolerance. The $CSR_{M\text{-}H}$ index calculated for the mild injury group indicated much more redundant variables than the $CSR_{A\text{-}H}$ calculated for athletes following ACL reconstruction. This means that functional deficits after ACL reconstruction were detected by more tests than in athletes after mild injuries. In other words, more tests were sensitive to post ACL reconstruction functional deficits (Table 2).

3.2.2. Multiple Regression Model When Part of the Redundant Variables (H/Q Ratio) Were Excluded

By eliminating redundant variables (H/Q ratio), the strength of other variables (tests) increased, indicating a stronger contribution of each test to the formation of the CSR index.

However, some tests still appeared redundant in the regression model, especially in the $CSR_{M\text{-}H}$ index (Table 3).

Table 2. Multiple regression model when all variables were included.

$CSR_{A\text{-}H}$	B	SE (B)	p	r	Tolerance	$CSR_{M\text{-}H}$	B	SE (B)	p	r	Tolerance
FMS	0.139	0.019	0.000	0.883	0.335	FMS	0.107	0.035	0.022	0.780	0.621
YBT IL	0.384	0.023	0.000	0.972	0.218	YBT IL	0.231	0.059	0.008	0.844	0.216
YBT UL	0.249	0.023	0.000	0.937	0.215	YBT UL	0.338	0.056	0.000	0.926	0.246
TJA	0.040	0.014	0.011	0.595	0.607	TJA	0.186	0.059	0.019	0.789	0.219
IT Ext IL	0.022	0.031	0.484	0.181	0.127	IT Ext IL	−0.161	0.456	0.736	−0.142	−0.009
IT Ext UL	0.295	0.075	0.001	0.709	0.021	IT Ext UL	0.113	0.132	0.421	0.332	0.023
IT Flx IL	0.150	0.021	0.000	0.879	0.274	IT Flx IL	0.427	0.392	0.318	0.406	0.030
IT Flx UL	−0.060	0.062	0.345	−0.243	0.031	IT Flx UL	0.035	0.187	0.857	0.076	0.005
IT H/Q IL	−0.008	0.035	0.811	−0.062	0.098	IT H/Q IL	−0.127	0.304	0.689	−0.168	0.008
IT HQ UL	0.229	0.055	0.000	0.728	0.039	IT HQ UL	0.176	0.105	0.144	0.564	0.069
HT SI	0.123	0.021	0.000	0.828	0.263	HT SI	0.152	0.051	0.025	0.770	0.291
HT IL	0.099	0.031	0.006	0.629	0.121	HT IL	0.130	0.068	0.106	0.612	0.162
HT UL	0.192	0.028	0.000	0.865	0.146	HT UL	0.125	0.081	0.174	0.531	0.115
R2 = 0.996; SE = 0.264; $p < 0.000$						R2 = 0.985; SE = 0.051; $p < 0.000$					

FMS—Functional Movement Screen; TJA—Tuck Jump Assessment; YBT—Y-balance Test; IT—Isokinetic Test; HT—Single Hop For Distance Test; IL—involved leg; UL—uninvolved leg; B—beta coefficient of regression; SE(B)—standard error of beta coefficient; p—partial significance for one variable; r—partial correlation coefficient; R2—multiple regression coefficient; red color indicates statistically significant variables in the model.

Table 3. Multiple regression model when part of the redundant variables (H/Q ratio) were excluded.

$CSR_{A\text{-}H}$	B	SE (B)	p	r	Tolerance	$CSR_{M\text{-}H}$	B	SE (B)	p	r	Tolerance
FMS	0.122	0.024	0.000	0.772	0.388	FMS	0.118	0.036	0.011	0.756	0.649
YBT IL	0.367	0.030	0.000	0.945	0.246	YBT IL	0.268	0.056	0.001	0.858	0.264
YBT UL	0.265	0.032	0.000	0.893	0.221	YBT UL	0.320	0.056	0.000	0.894	0.265
TJA	0.032	0.019	0.019	0.383	0.623	TJA	0.122	0.0475	0.032	0.673	0.377
IT Ext IL	0.050	0.024	0.050	0.454	0.393	IT Ext IL	0.007	0.087	0.933	0.030	0.110
IT Ext UL	−0.003	0.031	0.923	−0.023	0.238	IT Ext UL	−0.051	0.085	0.560	−0.209	0.116
IT Flx IL	0.158	0.024	0.000	0.843	0.384	IT Flx IL	0.200	0.068	0.018	0.721	0.184
IT Flx UL	0.171	0.035	0.000	0.764	0.186	IT Flx UL	0.325	0.075	0.002	0.836	0.150
HT SI	0.116	0.023	0.000	0.772	0.423	HT SI	0.120	0.044	0.027	0.688	0.425
HT IL	0.099	0.039	0.022	0.518	0.147	HT IL	0.147	0.069	0.068	0.596	0.174
HT UL	0.184	0.037	0.000	0.762	0.160	HT UL	0.085	0.069	0.253	0.399	0.176
R2 = 0.993; SE = 0.036; $p < 0.000$						R2 = 0.983; SE = 0.054; $p < 0.000$					

FMS—Functional Movement Screen; TJA—Tuck Jump Assessment; YBT—Y-balance Test; IT—Isokinetic Test; HT—Single Hop For Distance Test; IL—involved leg; UL—uninvolved leg; B—beta coefficient of regression; SE(B)—standard error of beta coefficient; p—partial significance for one variable; r—partial correlation coefficient; R2—multiple regression coefficient; red color indicates statistically significant variables in the model.

3.2.3. Multiple Regression Model When All Redundant Variables (H/Q Ratio and IT for Extension) Were Excluded

The excluded variables (IT for extension and H/Q ratio) were redundant in the model, which means that these tests did not have any predictive value in the construction of the CSR index (they did not contribute any information to the CSR index). In other words, the IT for extension and H/Q ratio were not sensitive for the detection of motor deficits post ACL reconstruction or post mild lower limb injury (Table 4).

Table 4. Multiple regression model when all redundant variables (H/Q ratio and IT for extension) were excluded.

$CSR_{A\text{-}H}$	B	SE (B)	p	r	Tolerance	$CSR_{M\text{-}H}$	B	SE (B)	p	r	Tolerance
FMS	0.139	0.024	0.000	0.793	0.452	FMS	0.122	0.031	0.022	0.779	0.771
YBT IL	0.388	0.03	0.000	0.942	0.272	YBT IL	0.281	0.050	0.000	0.870	0.295
YBT UL	0.237	0.030	0.000	0.871	0.292	YBT UL	0.312	0.047	0.000	0.902	0.336
TJA	0.026	0.020	0.023	0.281	0.653	TJA	0.120	0.042	0.017	0.669	0.418
IT Flx IL	0.157	0.026	0.000	0.810	0.401	IT Flx IL	0.185	0.051	0.005	0.748	0.277
IT Flx UL	0.186	0.025	0.345	0.863	0.438	IT Flx UL	0.301	0.054	0.000	0.866	0.248
HT SI	0.128	0.023	0.000	0.780	0.489	HT SI	0.111	0.030	0.004	0.753	0.790
HT IL	0.105	0.04	0.024	0.489	0.148	HT IL	0.162	0.063	0.028	0.629	0.186
HT UL	0.177	0.040	0.000	0.706	0.163	HT UL	0.061	0.057	0.312	0.318	0.225
R2 = 0.992; SE = 0.039; $p < 0.000$						R2 = 0.985; SE = 0.050; $p < 0.000$					

FMS—Functional Movement Screen; TJA—Tuck Jump Assessment; YBT—Y-balance Test; IT—Isokinetic Test; HT—Single Hop For Distance Test; IL—involved leg; UL—uninvolved leg; B—beta coefficient of regression; SE(B)—standard error of beta coefficient; p—partial significance for one variable; r—partial correlation coefficient; R2—multiple regression coefficient; red color indicates statistically significant variables in the model.

4. Discussion

The most important information from this study is that all tests significantly influenced the final CSR index, what means that these tests were indicative of functional deficits related to ACL reconstruction. However, for the Isokinetic Test, the strength of the extensor (quadriceps) muscle and the H/Q ratio appeared to be non-sensitive in assessing functional deficits related to ACL reconstruction. It was also presented that if the test battery included four to five tests, it better differentiated the athletes after ACL reconstruction from those after mild injuries, even if they were all cleared to play. It was shown in our study that the CSR index should be calculated from more than two tests, because this increases its accuracy.

There is no consensus in the literature about the number of tests that should be included in the RTS procedure, and some authors have recommended the easier protocol with less measurements, but others advised up to 15–20 different RTS tests to cover a broad range of ACL graft rupture risk factors [6,24]. According to literature on the subject, the RTS protocol should contain tests assessing various motor features, but if there are too many of them, a small percentage of the athletes pass them [6,51]. Other authors have suggested that the focus should be shifted towards identification of fewer but more predictive tests [52]. Moreover, if the number of tests is too large, there is a problem with an excessive amount of data, which may be difficult for the coaches to interpret, especially when they give divergent results. In our research, it has been noted that the optimal number of tests unequivocally indicating the presence of motor deficits after ACL reconstruction is four or five. Such a number of tests showed a significant difference in the CSR index value between players after ACL reconstruction and those who underwent mild lower limb injuries. A too-small number of tests (less than three) did not allow to differentiate the size of the motor deficits in either of the studied groups. Therefore, it seems reasonable that both too few or too many tests in the RTS protocol are not good, and each of them become vulnerable to errors.

There is no consensus on the components of RTS testing following ACL reconstruction or if passing RTS criteria can reduce the risk of re-injury [12,22]. Researchers have suggested that optimal cut-off scores (Isokinetic Strength and Hop Tests) for competitive athletes should be ≥90–100% LSI [23,53]. The most popular is the Single-Leg Hop Test, but its ability to alter second ACL injury risk and predict future knee injury has not been established [10,49]. The athletes, to confirm RTS readiness, should be able to hop on the reconstructed leg at least 90% of the distance hopped on the contralateral (uninvolved) leg [22,23,53]. A 90% LSI should be reached at 6 to 9 months postoperatively [12,53]. However, as underlined by some authors, the quantitative measurement (distance and LSI) may not provide enough information to optimize test sensitivity [54,55]. In addition, the LSI after ACL reconstruction may be misleading, because an athlete hops a shorter distance on the uninvolved limb, which is also weaker than the matched leg of a control group [23]. This implies that the uninvolved leg is significantly affected by the ACL injury, questioning the use of LSI as a criterion in RTS [54]. In our study, it has been shown that the Hop for Distance Test is a good assessment tool applied after ACL reconstruction, even if its partial correlation coefficients were lower than other tests.

The clinical usefulness of jump–landing mechanics when making RTS decisions have been previously reported [2,7,10]. The authors indicated that valgus loading and altered postural stability during landing tasks may be used to predict future injury [10,12,55]. This maintains agreement with our results, in which it was noted that TJA was a reliable and significant test differentiating athletes post ACL reconstruction from those following mild injuries.

Some authors have reported that quadriceps strength deficits pre-return to level 1 sport were a significant predictor of knee re-injury [12,54,55]. Thus, passing of the RTS test battery required meeting an LSI level >90% of isokinetic quadriceps and hamstring strength at 60°/s, 180°/s, and 300°/s [55]. Nonetheless, in their review paper Undheim et al. [56] concluded that isokinetic strength measures have not been validated as useful predictors of successful RTS. Other authors also found weak evidence supporting any associations between higher quadriceps strength and successful return to sport [10,12]. Kuenze et al. [57] reported that only 39.3% of the evaluated subjects passed the criterion for LSI quadriceps peak torque at 60°/s. Moreover, evidence in the literature allows to strongly indicate that quadriceps strength deficits are commonly observed for several months and years following ACL reconstruction [14,25,56]. The relative ratio between quadriceps and hamstring strength has been implicated in ACL injury and re-injury risk [57,58]. As was reported by Hewett et al. [59], the H/Q ratio related to increased risk of ACL injury was below 55% for females and less than 62.5% for males regarding the involved leg at 300°/s. In our study, isokinetic strength assessment significantly differentiated athletes following ACL reconstruction from those with mild injuries, but not all parameters were equally significant. Only the strength for the knee flexor muscles was a relevant test. An important observation is that neither quadriceps (knee extensor) strength nor H/Q ratio were significant components of the CSR index. These tests appeared to be redundant in the model, which means that the provided information about functional deficits was of little value. Therefore, we suggest that quadriceps strength and H/Q ratio should not be used in RTS testing after ACL reconstruction. The strength of the hamstring muscles was much more indicative of functional deficits. Knee extensor muscle strength and H/Q ratio are useful indicators of progress in rehabilitation, especially in the early period after ACL reconstruction. However, in the long term, the greatest deficits occur within the flexor muscles (hamstrings), and therefore isokinetic assessment within this muscle group seems more reasonable.

In addition, incorporation of movement analysis in detecting asymmetrical movement patterns after ACL reconstruction prior to releasing an athlete to the high demands of sports has been suggested [60]. In our study, movement quality was assessed via the FMS test and demonstrated to be significant, but had relatively low diagnostic value in the evaluated footballers.

This study also has some limitations which should be addressed. We calculated the CSR only from tests assessing motor deficits. We did not evaluate psychological factors, which are also important in the RTS process. Therefore, there is a need for future research, including psychological readiness measurement, which could cause the CSR itself to be more comprehensive. In addition, the study design was observational, and the football players were evaluated only once, thus, there is a need for future research including longitudinal monitoring of factors related to ACL re-injury.

5. Conclusions

We observed that all tests significantly influenced the final CSR index, which means that these tests are indicative of functional deficits related to ACL reconstruction. The Y-balance Test, Tuck Jump Assessment, and Isokinetic Test for knee flexion influenced the final CSR index the most, which means that these tests are mostly indicative of functional deficits related to ACL reconstruction. The strength of the extensor (quadriceps) muscle and the H/Q ratio appeared to be non-sensitive to testing functional deficits concerning ACL reconstruction. The CSR should be calculated from more than two tests because this increases accuracy. If the test battery includes four to five tests, it better differentiates the athletes after ACL reconstruction from these following mild injuries, even if they were all cleared to play. The CSR index seems to be a useful tool for monitoring athletes returning to sport post ACL reconstruction. There is a need for future research including longitudinal monitoring of factors related to ACL re-injury. In addition, players from amateur and semi-professional clubs should be evaluated as well as athletes from different sport disciplines with high level of ACL injury. Moreover, the usage of one index score obtained from multiple tests should be more comprehensively assessed and implemented for daily couching practice. The creation of a normative database from multicenter studies from tests used in RTS would also be of interest.

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