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Can A Repeated Sprint Ability Test Help Clear A Previously-Injured Soccer Player For Fully Functional Return To Activity? A Pilot Study

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Abstract

Objective: To investigate the effects of fatigue induced by a repeated sprint ability test (RSA) on the neuromuscular responses of soccer players with a recent history of lower limb injuries (CH) and a matched control group in good fitness condition (GH).

Design: This was a case–control study.

Participants: Nine CH and nine GH.

Independent Variable: Allocation to CH or GH.

Main Outcome Measures: Each player was assessed for blood lactate concentration (BLa), jumping performance (squat jump/SJ, counter-movement jump/CMJ) before/after RSA. Post-RSA perceived exertion (RPE) was obtained. Receiver operating characteristic analysis was performed to calculate RSA sensitivity and specificity in distinguishing between CH and GH. Intraclass **c**orrelation **c**oefficient (ICC) was used to assess reliability.

Results: No baseline differences were found for any variable. ΔSJ before/after RSA was -14±2%, -5±2% in CH and GH, respectively (P<0.05). ΔCMJ before/after RSA was -15±2%, -7±2% in CH and GH, respectively (P<0.05). ΔSJ-, ΔCMJ-based (before/after RSA) area under curve (AUC) resulted in 0.9**0**±0.07 and 0.8**6**±0.09, respectively, with both AUCs differentiating between CH and GH with 77.78**%** sensitivity **and** 88.89**%** specificity. Pooled AUC resulted in 0.88±0.0**6**. ICC was high (0.85÷0.97).

Conclusions: RSA is a simple, low-cost field test potentially able to assist in clinical decision-making for return-to-sport.

Key Words: lower limb injury; neuromuscular fatigue; team sport; functional recovery.

INTRODUCTION

One of the main challenges in the rehabilitation process of sport-related injury is determining whether and/or when the athlete may safely return to demanding, strenuous physical activities.[1] The criteria that should be confirmed at a satisfactory level before an injured athlete may return to play includes the status of anatomical and functional healing, and the restoration of sport-specific skills. The enforced inactivity caused by an injury reduces physical capabilities,[2] therefore functional rehabilitation programs should be designed in such a way that players can regain – to as great a degree as possible – their pre-injury fitness level.

By considering a variety of muscle function indices and functional scores, functional outcome measures can quantify players' performance capabilities and can verify whether the athletes are able to return to sport. Performance capabilities below pre-injury level may reflect an incomplete functional recovery and may therefore potentially lead to re-injury. The evaluation of performance outcomes after an injury is often limited to strength assessment[3] or to functional hop tests.[4] Despite the reliability and validity of these tests,[5] several issues should be considered when interpreting their sensitivity for detecting functional limitations caused by sport injuries especially due to the fact that such tests are not designed to investigate repeated performance.[6]

Several studies have examined the relationship between gold standard methods outcomes (ie, strength tests, single hop and multiple hop tests) and measures of functional performance, including sprint,[7] repeated sprint ability[8] and vertical jump.[9] Unfortunately, the low to moderate shared variance denotes that these tests tend to be widely independent.[9] Moreover, these tests are rarely performed under fatigue conditions, which questions their validity at verifying the readiness of injured players to return to full activity. These tests might give false negatives just because their lack of repeated physical exertion.

The ability to perform sport activities under fatigue conditions is of great importance,[10] as injuries often occur towards the end of a sporting event when a participant is fatigued.[11] Therefore, to better evaluate the effectiveness of training or rehabilitation interventions, testing under fatigue conditions should be encouraged.[12] A major fitness component for successful participation in team sports is repeated sprint ability, ie, the ability to recover and to maintain maximal power/speed over a series of high-intensity sprints, coping with repeated bouts of high-intensity exercise and effort. The repeated sprint ability test (RSA) was validated in team sports with different distances and number of sprints including basketball, soccer, and handball,[13–15] depending on the nature of the sporting endeavor. RSA allows an ecological performance evaluation specific to most popular field-based team sports.[16] Indeed, the changes of direction (COD) related to the braking and acceleration phases demonstrate the players' effort in terms of high muscle solicitation of the lower limbs.[14,15] Furthermore, with RSA it is possible to calculate the Fatigue Index (FI)[17], which is due to a combination of both central and peripheral determinants. However, to our knowledge, while the reliability and validity of some tests have been reported, there has been no published attempt to date to assess the sensitivity of RSA in confirming the functional recovery status in previously-injured athletes.

This study investigated the neuromuscular responses under an RSA-induced fatigue condition, as a proxy for ecological gameplay, in a small sample of soccer players who had experienced lower limb injuries and, after attending a 3-month rehabilitation program and a 3-month soccer-training program, were considered to be clinically healthy (CH). A sample of soccer players in good health (GH) was used as a comparison. We hypothesized that such a study protocol could provide indications about different functional capabilities under fatigue conditions between the two samples.

METHODS

Participants

Inclusion criteria were: inclusion in First National Ranking soccer practice, 5.4±1.2 years training, ~8 hours/week of training, being clinically healthy (i.e., cleared for return to play by the team physician) after attending (post-injury) an injury-specific 3-month rehabilitation program and a standard 3-month soccer-training program[18] (CH; ie, they were tested 6 months after their injuries), or no injury history (GH). The CH participants' previous histories of injury were related to: pubalgia (1 subject), left adductor strain (1 subject), right hamstring strain (2 subjects), right knee sprain (1 subject), 1st degree left ankle sprain (1 subject), 2nd degree left ankle sprain (2 subjects), and 2nd degree right ankle sprain (1 subject). The participants belonged to the same team, were accustomed to shuttle running, and were participating in the national championships at the time of the investigation. The participants were homogeneous with regard to training status, and were not participating in any strenuous endurance activity or resistance training outside their training schedule. Written consent was obtained from the participants' parents/guardians and all experimental procedures were approved by the Committee Human Research Ethics Board.

Procedures

Outdoor field tests were completed on a certified synthetic turf pitch, with players wearing soccer shoes at the same time of day.[19] The average weather conditions were as follows: average wind speed ~0.8 $m \cdot s^{-1}$, temperature ~22°C when the testing session started at 2:00 p.m., and ~23°C when the testing session ended at ~3:00 p.m..

A two-group repeated-measures study design was used with time as independent variable, whereas sprint times, jump performances, blood lactate concentration (BLa) and rate of perceived exertion (RPE) were dependent variables. The experiment was performed on two days, with four days in between each testing session. On the first and second testing days the participants performed a standard RSA.[20] No additional strength, power and/or plyometric training was performed during the testing period.

Each player underwent squat jump (SJ) and counter-movement jump (CMJ) as lower limb neuromuscular assessments: SJ and CMJ values, BLa and RPE were analyzed at the following time points. Before the RSA session, each soccer player was assessed for BLa and jumping performance. BLa and jumping performance were then assessed 3-minute after the RSA session, using the same procedure. Jumping performance was further assessed 10-minute after the RSA session. RPE was assessed 30-minute after the RSA session.[21,22] Four days later, all tests were repeated to calculate the **i**ntraclass **c**orrelation **c**oefficient (ICC).

Repeated Sprint Ability Test

During each session, the participants completed a standardized repeated sprint ability test (RSA) session[20] consisting of six maximal 40 m shuttle-sprints (20 m forth+180° change of direction [COD]+20 m back) separated by 20-s recoveries. The time for each single shuttle sprint was recorded using a Brower Timing System (Salt Lake City, UT, USA; 0.01-s accuracy). To balance the physical effort of the legs during CODs in all RSAs, each participant was asked to alternate the leg that was used to start the COD.

Fatigue Index (FI) was calculated by using the Fitzsimons' formula:

$$FI=100\times(TT/(BT\times6))-100),$$

where TT corresponds to total time and BT to the best sprint time.[17]

Vertical Jump Tests

To assess the individual vertical jump performance[23,24] just before and after RSA, SJ and CMJ were performed randomly, and the height of each jump (in cm) was measured using

Optojump™ (Microgate, Bolzano, Italy)[25]. Within a preliminary session, familiarization trials were completed until the correct technique was achieved. All players performed two repetitions of both SJ and CMJ, with 1-minute passive rest in-between.

Rate Of Perceived Exertion Assessment And Blood Lactate Sampling

Before and three minutes after the end of RSA a blood sample was assessed.[26] BLa ($mmol \cdot L^{-1}$) was measured with Arkray Lactate Pro LT-1710 (Kyoto, Japan). The subjects were also instructed on the proper use of RPE until they demonstrated good understanding.[22]

Statistical Analysis

Descriptive values were computed as mean±standard deviation (SD) for continuous variables. Range was also reported. Normal distribution was controlled with the one-sample Kolmogorov-Smirnov test with Lilliefors significance correction. Differences in BLa, SJ and CMJ scores obtained for each RSA were compared between and within the two sample groups, using a repeated-measure analysis of variance with a grouping factor and with time as the repeated measure. The normality, the homogeneity of covariance matrices, as well as the independence and the sphericity assumptions were checked to make sure that they were met. Mauchly's test was used to check for sphericity. If the sphericity assumption was violated ($P>0.05$), the Greenhouse-Geisser's correction was applied to adjust the degree of freedom for the test of the interaction effect between different time points and different sample groups. If the ε value was less than 0.75, otherwise, the Huynh-Feldt correction was used. In case of sphericity violation, also the results of the multivariate analysis (namely, the Pillai's trace, Wilks' λ, Hotelling's trace and Roy's largest root) were reported. Partial η^2 and observed power for each parameter were also computed. *Post-hoc* tests were performed using Šidák correction for multiple comparisons. Pearson's correlation was computed to correlate RPE with the other variables.

Receiver Operating Characteristic (ROC) analysis was performed to calculate the sensitivity and specificity of RSA in distinguishing between CH group and GH group, that is to say the ability to discriminate between previously injured and non-injured players. Areas under curves (AUC) were pooled and heterogeneity was estimated using the Q and the I^2 statistics. The Youden's index was used to determine the best cut-off point in order to separate CH from GH with acceptable sensitivity and specificity. Figures with a $P<0.05$ were considered statistically significant. All statistical analyses were performed using SPSS for Windows (version 22.0, Chicago, IL, USA).

RESULTS

Eighteen young male soccer players (9 CH+9 GH, age 16.5±0.5 yrs, mass 65.0±8.5 kg, height 1.72±0.10 m, BMI 21.79±2.40 kg) participated in this study. No differences could be found between the two groups regarding RSA performance (Figure 1, Table 1). FI did not differ between CH and GH ($P>0.05$). Before the RSA session, no differences were found for each studied variable (Table 1).

For SJ, the between-effect was not significant (F=2.51, $P>0.05$, partial η^2=0.1**4**, observed power=0.32), while the within-effect was significant for the factor (F=21.96, Greenhouse-Geisser adjusted $P<0.001$, η^2=0.5**8**, observed power=**1.00**) and the group-factor interaction (F=4.91, Greenhouse-Geisser adjusted $P<0.05$, η^2=0.2**4**, observed power=0.63). Three-minute SJ was different from SJ ($P<0.001$) and 10-minute SJ ($P<0.05$), while SJ and 10-minute SJ were not ($P>0.05$). The effect of SJ, the Pillai's trace, Wilks' λ, Hotelling's trace and Roy's largest root are reported in Table 2.

Th**e change from the baseline SJ to the th**ree-minute SJ **was statistically different for** the two groups ($P<0.05$, Figure 2). 3-minute ΔSJ in CH was -14±7%, while in GH it was

-5±5%. Ten-minute ΔSJ differed between the two groups ($P<0.05$, Figure 2). 10-minute ΔSJ in CH was -3±2%, while in GH it was 0±5%. ΔSJ before and after the RSA session was -14±2% and -5±2% in CH and GH, respectively ($P<0.05$), while ΔSJ before and 10-minute after RSA was -3±1% and 0±2% in CH and GH, respectively (not significant). ΔSJ–based (before and after RSA) AUC was 0.9**0**±0.07 (Figure 3, 95% CI 0.66-0.9**9**, z-statistic 5.38, $P<0.001$), and could differentiate between CH and GH with a sensitivity of 77.78**%** and a specificity of 88.89**%** (Youden's index=0.67, ΔSJ cutoff -9.0%).

For CMJ, the between-effect was not significant (F=3.14, $P>0.05$, partial $\eta^2=0.164$, observed power=0.385), while the within-effect was significant for the factor (F=50.48, Greenhouse-Geisser adjusted $P<0.001$, partial η^2=0.7**6**, observed power=1.00) and the group-factor interaction (F=5.22, Greenhouse-Geisser adjusted $P<0.05$, partial η^2=0.2**5**, observed power=0.6**9**). Three-minute CMJ differed from CMJ and 10-minute CMJ ($P<0.001$), while CMJ and 10-minute CMJ did not ($P>0.05$). The effect of CMJ, the Pillai's trace, Wilks' **λ**, Hotelling's trace and Roy's largest root are reported in Table 2.

Three-minute ΔCMJ differed between the two groups ($P<0.05$). Three-minute ΔCMJ among CH was -15±5%, while among GH it was -7±5%. Ten-minute ΔCMJ did not differ between the two groups ($P>0.05$). Ten-minute ΔCMJ among CH was -1±3%, while among GH it was 0±4%. ΔCMJ before and after the RSA session was -15±2% and -7±2% in CH and GH, respectively ($P<0.05$), while ΔCMJ before and 10-minute after RSA in CH and GH was -1±1% and 0±1%, respectively (not significant). ΔCMJ (before and after RSA)-based AUC was 0.8**6**±0.09 (Figure 3, 95% CI 0.6**2**-0.9**8**, z-statistic 3.88, $P<0.001$), and could differentiate between CH and GH with a sensitivity of 77.78**%** and a specificity of 88.89**%** (Youden's index=0.67, ΔCMJ cutoff -10.0%). Considering both ΔSJ and ΔCMJ, the pooled AUC was 0.881±0.057 (Figure 3, 95% CI 0.7**7**-0.99, z 15.3**4**, $P<0.001$; Q 0.**10**, I^2 0.00%). The average positive likelihood ratio using the SJ and CMJ tests was 7.0.

For BLa, the between-effect was not significant (F=0.0**4**, *P*>0.05, partial η^2=0.00, observed power=0.05), while the within-effect was significant for the factor (F=231.22, Huynh-Feldt adjusted *P*<0.001, partial η^2=0.9**4**, observed power=1.00) but not for the group-factor (F=0.1**7**, Huynh-Feldt adjusted *P*>0.05, partial η^2=0.01, observed power=0.07) interaction. The effect of BLa, the Pillai’s trace, Wilks’ λ, Hotelling’s trace and Roy’s largest root are reported in Table 2.

Reported fatigue (Table 1) differed between the two groups (*P*<0.05). RPE correlated with 3-minute CMJ (r=-0.5**3**, *P*<0.05), with 3-minute SJ (r=-0.47, *P*<0.05), with ΔSJ at 3 minute (r=-0.48, *P*<0.05), and with 10-minute ΔSJ (r=-0.**50**; *P*<0.05). ICC was high (range 0.85÷0.97).

DISCUSSION

Study Findings

This study assessed the sensitivity, reliability and validity of RSA for confirming the functional recovery status in injured soccer players (CH), by comparing their neuromuscular responses under a fatigue condition with a matched sample of healthy subjects (GH). RSA is a validated exercise/test for evaluating the ability to perform sport activities under fatigue conditions in team sports. Subjects were considered to be CH after they underwent a 3-month rehabilitation program and a 3-month soccer-training program. A detailed examination of a typical and specific RSA was conducted under controlled conditions, to assess whether a decrease in vertical jump height and an increase in RPE could be used as an objective indicators of the extent of neuromuscular fatigue induced by the aforementioned RSA. Firstly, our results indicated that by monitoring vertical jump heights following RSA, it is possible to reasonably estimate the neuromuscular fatigue induced by RSA action and consequently discriminate between CH and GH. Secondly, RPE was significantly higher in

CH following the RSA session, and, further, correlated with both jump heights. Study findings showed that investigating the neuromuscular responses under an RSA-induced fatigue condition provides indications about different functional capabilities between CH and GH.

Injury Recovery And High Intensity Activities

This investigation is, to our knowledge, the first to compare the effects of RSA on neuromuscular performances between CH and GH. Nevertheless, the results confirm previous investigations assessing the mechanical and metabolic variables directly related to performance during repeated sprint efforts.[27,28] Evidence suggests that the incorporation of movements involving the stretch shortening cycle (SSC)[29] provides a specific examination of neuromuscular fatigue.[30] For instance, there is a strong relationship between the CMJ and sprint ability,[31] and CMJ is a good surrogate for the mechanical power of the lower body.[32] This confirms the agreement between biomechanical analyses of sprinting, which report that the short-distance sprint is highly dependent on the subject´s ability to produce powerful extensions of the knee and hip extensor, and analyses of the plantar-flexors muscles[33] as reported about vertical jumps. Neuromuscular fatigue has been described as any exercise-induced reduction in the maximal voluntary force or power produced by a muscle or a muscle group,[34] and is dependent upon the type of muscle contraction, and the intensity and the duration of the exercise.[35]

Traditionally, neuromuscular fatigue has been examined using isolated forms of isometric, concentric or eccentric movements.[34,36] However, evidence suggests that the incorporation of movements involving SSC[29] provides a more specific examination of neuromuscular fatigue;[30] therefore, CMJ height decrease could be used as an indicator of neuromuscular fatigue.[28] In addition, such performance variables have been used in team sports to determine the effect of competitive team match play on neuromuscular fatigue.[37]

Comparing previous investigations and the present study is difficult, since the protocols used to induce fatigue, the samples, and the type of actions and movement speeds differ greatly among studies. Nevertheless, in general CMJ height decrease can be used as indicator of neuromuscular fatigue. Joint motion and muscle activity of the trunk and lower limb are essential for effectively performing an optimal linear locomotive performance.[33] However, since the kinetic chain is a complex, multi-segmented system involving the trunk, pelvis, lower limbs and upper extremities, abnormal mechanical demands may affect the biomechanical responses in the kinetic chain, including a pre-injured structure, which may contribute to a reduction in functional performance.

Injury Recovery And Metabolic Counterparts

Previous studies have examined metabolic response and fatigue development during repeated intense exercise,[38] demonstrating a strong correlation between low levels of muscle glycogen and pH, and a decrement in force and power.[39] In addition, high intensity is characterized by an increased blood ammonia level and a low ATP/ADP ratio.[40] As such, ammonia is an indicator of muscle fatigue because of its negative effects on exercise, causing an alteration of neuromuscular activity and local muscle fatigue.[41] Furthermore, ammonia may reach the brain and cause a detrimental effect on central nervous system functions.[40] Therefore, BLa[30] and blood ammonia levels[40] can be used as indicators of exercise intensity. However, our study did not show any association between lactate or kinematic variables and jump performances.

The current study indicated that both groups produced similar BLa at the end of RSA. This finding suggests that such a product of the glycolytic metabolism may not be targeted as a limiting factor for subsequent vertical explosive performances. Since fatigue has traditionally been defined as a loss of force-generating capability, with an eventual inability to sustain exercise at the required or expected level,[35] the affected explosive performance of CH following RSA may result from impairment in neuromuscular properties such as muscle shortening velocity (which decreases) and relaxation time (which increases)[42]. These factors will be affected due to fatigue, and considering the observed decline in vertical jump height when analyzing the SJ and CMJ height decrease after RSA, we could consider such a vertical jump-height decrease as equivalent to a muscle-shortening speed decrease.[28] The association between RPE and jumping height is in agreement with findings reported by Asadi in a systematical study of the literature.[43]

A performance profile should encompass physiological, biomechanical and performance measures pertinent to the athlete`s discipline and the required functional ability. A combination of physical variables is often used for talent identification, the creation of normative standards and performance tracking to predict an athlete’s ability to excel in a particular sport or athletic discipline. Our study is the first to use a standard field RSA to confirm the recovery status in CH by comparing the neuromuscular responses under a fatigue condition. The RSA is a simple, reliable and low-cost field test potentially able to assist in clinical decision-making for return-to-sport.

Limitations of the Study and Suggestions for further Studies

The findings from this study may be relevant for a CH group tested after the **prescrib**ed post-injury interval, which is however realistic for young and high-level soccer players. Ideally, the same cohort or a new group could be tested after a longer interval in order to assess the stability of the findings of this study independent of injury. To strengthen the findings of this study for clinicians, it could be useful to gather data on subsequent injury rates of CH and to use a larger sample. The comparison between the correlation between CH test results and re-injury likelihood, and the correlation between GH test results and injury likelihood should be investigated. Finally, the approach featured in this study may not be generalizable to all ages and should be specifically applied with adult soccer players to tailor it to them.

CONCLUSIONS

The current literature regarding the evaluation of performance outcomes after an injury is often limited to standard strength assessment[3] or to functional tests[4] whose ecological validity and sensitivity are questionable. Following any injury and during the ongoing rehabilitation process, athletes are still predisposed to a subsequent re-injury. Consequently, several factors should be considered for detecting the residual functional limitations caused by the enforced inactivity in order to provide an objective evaluation of the athlete`s readiness.[6]

The current study revealed the RSA-based approach potentially useful in providing physicians and athletic trainers with an additional tool, specific and sensitive in profiling the athlete’s rehabilitation process and the consequent readiness to return to full activity participation. However, given the limitations of this study, further research in the field using larger samples is needed.

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Figure Legends

Figure 1: Sprint times for the two groups (in grey, previously-injured athletes/clinically healthy players – CH; in white, not previously-injured athletes/players in a good health condition – GH).

Figure 2: Squat jump (SJ) and counter-movement jump (CMJ) height post- *vs.* pre-RSA percent decreases for the two groups (in grey, previously-injured athletes/clinically healthy players – CH; in white, not previously injured athletes/players in good health condition – GH). "*" $P<0.05$.

Figure 3: Receiver operating characteristic (ROC) analysis for evaluating the potential of the used repeated sprint ability test (RSA) in distinguishing between clinically healthy players and players in good health condition. ROC curves are based on decreases in squat (SJ) jump and counter-movement jump (CMJ) before and after RSA.