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The Impact of a Novel Neuromuscular Training Program on Leg Stiffness, Reactive Strength, and Landing Biomechanics in Amateur Female Rugby Players

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Abstract: This randomized control study aimed to assess 12 weeks of a novel neuromuscular training program (KneeRugbyWomen) on jump-related biomechanical variables in amateur female rugby players. Twenty-four participants were randomly allocated to either an experimental group (EG; n = 12, age: 20.05 ± 4.43 yrs., height: 166.54 ± 4.46 cm, weight: 64.65 ± 6.44 kg) or a control group (CG; n = 12, age: 20.04 ± 4.88 yrs., height: 166.83 ± 7.30 cm, weight: 69.83 ± 12.84 kg). Participants were tested before and after a 12-week intervention for jump-related biomechanical variables (leg stiffness, Reactive Strength Index (RSI), and landing mechanics using the Landing Error Scoring System (LESS)). A significant increase in RSI was found in EG (p = 0.012, r = 0.70, large effect). At post-testing, players in EG had significantly greater RSI scores compared to CG at post-intervention (p = 0.007, r = 0.55, large effect). LESS scores of CG were significantly greater compared to EG at pre-intervention (p = 0.008, r = 0.55, large effect) and post-intervention (p = 0.003, r = 0.60, large effect). Results of this study demonstrate a positive effect of the KneeRugbyWomen training program on RSI, which has been previously associated with increased ACL injury risk in female players.

Keywords: injury prevention; jumping; risk factors; injury; anterior cruciate ligament

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Citation: Sikora, O.; Lehnert, M.; Hanzlíková, I.; Hughes, J. The Impact of a Novel Neuromuscular Training Program on Leg Stiffness, Reactive Strength, and Landing Biomechanics in Amateur Female Rugby Players. *Appl. Sci.* **2023**, *13*, 1979. https://doi.org/10.3390/app13031979

Academic Editors: Marcin Maciejczyk and Przemysław Bujas

Received: 14 December 2022
Revised: 27 January 2023
Accepted: 1 February 2023
Published: 3 February 2023

1. Introduction

Rugby Union is a sport with a high incidence of injuries compared to other contact sports [1]. Knee injuries are a common injury in rugby [2,3], specifically to the anterior cruciate ligament (ACL), which require long periods of rehabilitation, a high likelihood of re-injury and earlier degenerative changes to the knee [4–7]. Females are at approximately six times greater risk of non-contact ACL injury compared to males [8,9], with two-thirds of these ACL injuries of non-contact origin [10]. This risk is further heightened for adolescent female players [11], in particular between 15–19 years old [6], coupled with a higher incidence of re-injury [7]. Moreover, Takazawa et al. [7] observed that adolescent rugby players show greater match play level decrements following ACL injury compared to older players.

ACL injuries occur mainly due to the failure of dynamic stabilizing structures rather than passive stabilizing structures [12]. Proper muscle and neuromuscular control elicit dynamic stability of the knee, reducing the risk of ACL injury [4,13]. A deficit in neuromuscular control is considered a relevant risk factor for lower limb injuries and is linked to lower sport-specific performance [14]. In rugby, most ACL injuries occur during jumping, single-leg landing, or sudden change of speed or direction [15]. Both in terms of performance and injury prevention, most of these specific rugby movements require efficient stretch-shortening cycle (SSC) action. SSC is associated with strong neuromuscular coordination and muscular power production in the lower limbs [16]. Reactive strength, assessed by the Reactive Strength Index (RSI) using field-based testing, has been considered a reliable measure of SSC capability [17]. It is considered an indicator of ACL injury risk [18], and it is suggested that low RSI values indicate poor SSC function [19] and further discriminate between playing abilities, as elite players have more effective contact times than non-elite players [20]. SSC efficiency can also be assessed by means of leg stiffness, with greater values of leg stiffness demonstrating an increased ability of the dynamic mechanisms to generate rebound movements during the SSC [21] and reduce the load on the ACL [12]. Further, there is evidence to support that females have both lower values of absolute leg stiffness (ALS) [22,23] and RSI [24,25] compared to male athletes, supporting the rationale for the increased risk of injury in this population.

Effective landing biomechanics help reduce mechanical forces on the knee, specifically reducing the load on the ACL, decreasing the risk of injury [26]. The ankle, knee, hip, and trunk cooperate to absorb force on landing [27], with soft landings being more effective in absorbing greater mechanical forces as they are accompanied by higher angles of hip, knee, and ankle flexion compared to stiff landing [28]. Moreover, a knee flexion angle lower than 30° increases tension on the ACL [9], increasing non-contact injury risk. Compared to males, typically, we see greater evidence of dynamic knee valgus in females [27,29] with a contralateral pelvic drop, internal femoral rotation, knee valgus, tibia internal rotation and foot pronation. A widely utilized and valid diagnostic tool for assessing injury risk during landing is the Landing Error Scoring System (LESS) [30]. The test has good levels of reliability in the field and has detected individuals at greater risk of non-contact ACL injury during landing tasks [31].

Recent evidence has demonstrated that high-quality prevention programs [11] can reduce non-contact knee injuries by up to half [32,33]. Effective prevention programs in both male and female athletes often include static and dynamic balance, strength and power development of the lower limbs and plyometric activities [14,32,34–37]. This has subsequently been confirmed in a recent systematic review [38] stating that it is appropriate to combine balance, strength and plyometrics for a more effective prevention program. However, a comprehensive prevention program should also focus on the landing skills of the athlete, especially in female team sports [31,39,40].

Studies exploring injury prevention programs in rugby to date have focused mainly on male players [41–43], and to our knowledge, there are no studies exploring the efficacy of injury prevention programs in amateur female rugby players. Therefore, our aim was to compare leg stiffness, RSI, and LESS scores before and after a novel 12-week KneeRugbyWomen training program for amateur female rugby players. We hypothesized that the program would increase leg stiffness and RSI and decrease LESS scores on completion of the 12-week training.

2. Materials and Methods

2.1. Participants

A priori sample size calculations were performed using G*Power 3.1.9.7. We applied a standard two-tailed hypothesis equation, 80% power ($\beta = 0.20$), 5% significance level ($\alpha = 0.05$), and data from previous studies [44,45] to calculate sample size requirements. Both studies examined the efficiency of injury prevention training programs on athletes. The first study focused on the effect on LESS scores [45], while the second study analyzed the effect on relative leg stiffness [44]. The calculations specified a sample size of between 16 to 21 participants was required to identify the difference between the groups for pre- and post-intervention for mean LESS scores and leg stiffness. To ensure suitable statistical power if there was missing data or a potential dropout rate of 30%, 31 participants were recruited.

A group of 31 amateur female Rugby Union players from two clubs volunteered to participate in the study. The athletes had to be a minimum of 15 years old, free of serious knee injury in the 6 months before testing and actively participate in Czech amateur rugby competitions. The players were randomly allocated to a condition in a counterbalanced manner to either an experimental group (EG, $n = 16$) or a control group (CG, $n = 15$). Seven players were not present at pre- or post-intervention testing or did not participate in at least

80% of training sessions. According to the analysis, these players were missing at random (i.e., not significantly different from the remaining players in any variable measured) and therefore were not included in the final analysis. The final sample of 24 players was analyzed, 12 in the EG (mean ± SD: age, 20.05 ± 4.43 yrs., height, 166.54 ± 4.46 cm, body mass: 64.65 ± 6.44 kg) and 12 in the CG (mean ± SD: age, 20.04 ± 4.88 yrs., height: 166.83 ± 7.30 cm, body mass: 69.83 ± 12.84 kg). On average, the players trained 3 times a week, 90 min per session. The players were instructed not to participate in any vigorous activity 48 h prior to the testing.

Prior to participation, all procedures involved in the experimental design and the potential risks were explained fully, both verbally and in written form, to participants and parents (when below 18 years old). To use the data for further research, written informed consent was gained from both players and parents, where necessary. Prior to inclusion in the study, participants completed a health questionnaire. The study conformed to the Declaration of Helsinki regarding the use of human subjects and was approved by the Institution's ethics committee.

2.2. Procedures

A randomized control study design was used to determine the effects of the KneeRugbyWomen training program on leg stiffness, RSI, and LESS scores in female rugby players. Participants performed pre-intervention testing a week before the intervention started and post-intervention testing immediately after 12 weeks of training (Figure 1). In both testing sessions, the RSI and leg stiffness were obtained using Optojump Next (Microgate, Bolzano, Italy), an optical timing system that has been deemed to have an accuracy of 0.001 s, according to the manufacturer's specifications. Single-leg countermovement jumps (SL CMJ) were obtained via the use of 2 video cameras (Sony HXR-NX5E, Sony Corporation, Tokyo, Japan) capturing at 25 Hz. The videos were used to assess landing biomechanics using the LESS [46]. Additionally, at the beginning of both testing sessions, body mass was measured using InBody770 (Biospace, Seoul, South Korea) and standing and sitting height using a stadiometer A-226 (Tryston, Olomouc, Czech Republic). Participants wore their own athletic footwear during all testing except anthropometric testing.

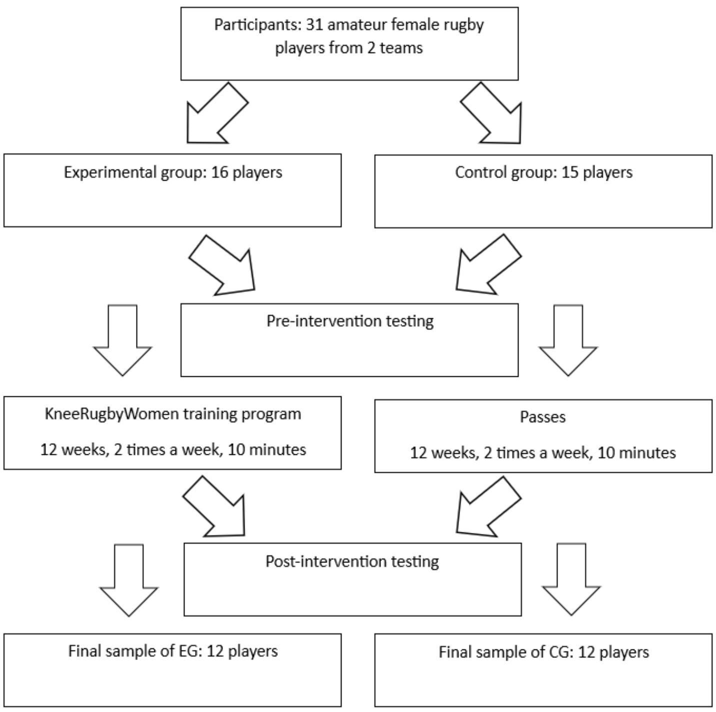

Figure 1. Study flow chart.

2.2.1. Leg Stiffness

The calculations for both ALS and RLS were obtained from the contact time data collected during a bilateral submaximal hopping protocol [19]. Participants undertook three sets of 20 bilateral submaximal hopping at 2.5 Hz frequency. The frequency of hopping was maintained via an audio signal from a quartz metronome (WITTNER, Isny, Germany). Instructions to participants were to keep hands on the hips, take off, and land in the same place, keeping the lower limbs fully extended on landing and keep looking forwards at a fixed position. Participants had a 2-min rest between sets. Leg stiffness (kN/m^{-1}) was calculated from body mass (kg), flight time (ms) and contact time (ms) parameters obtained from the average of the 6th–15th test hops. The mean values from the three sets were utilized for subsequent statistical analysis. The ALS data were determined via the equations of Dalleau, Belli, Viale, Lacour and Bourdin [47]. RLS was calculated by dividing ALS by body mass and lower limb length (assessed as a difference between standing and sitting height) to provide a dimensionless value [17,19]. This method has been shown as valid and reliable [17,19,47].

2.2.2. Reactive Strength Index

RSI (m/s) was obtained during a 5 maximum hop test. The RSI variable was calculated using the equation of Flanagan and Comyns [20]. The starting position was the same as described in the 20 submaximal bilateral hopping protocol. The participants were told to jump as high as possible whilst minimizing their time on the ground. Participants completed three sets of jumps interspersed by a 2-min recovery. During all sets, the initial jump was a countermovement jump and therefore was removed from the calculation. The four remaining hops were averaged for RSI analysis. The set with the highest mean was used for the statistical analysis. This method has been previously shown as valid and reliable [19].

2.2.3. Landing Error Scoring System

Participants performed three SL CMJ trials according to previously published protocols [48]. Specifically, participants were instructed to take 2 steps forwards, immediately jump as high as possible, imagining reaching for a ball above their head and performing the task in one fluid motion. Participants were given as many practice trials as needed to become comfortable with the task. No feedback on the landing technique was given, and participants were only provided feedback if they were performing the take-off section of the task incorrectly. Participants had a two-minute rest between trials. In all instances, the SL CMJ was obtained from two video cameras placed 3.5 m in front of and to the right side of the landing area; the cameras were fixed on tripods with a lens-to-floor distance of 1.3 m. One qualified rater, who was not blinded to the pre- and post-intervention time points, analyzed all videos with Kinovea software (version 0.8.15, https://www.kinovea.org/, accessed on 17 March 2022), scoring all 3 SL CMJ trials with the 17-item LESS scoring sheet [46]. The rater obtained the mean LESS score of the three trials that were subsequently utilized in statistical analysis [49].

2.2.4. Training Intervention

The 12-week training intervention was performed two times a week. The CG did a standard warm-up for 15 min followed by 10 min of rugby-specific passing drills. The EG did the same warm-up as the control group, followed by 10-min of the KneeRugby-Women program.

The KneeRugbyWomen program was created by researchers following current trends in injury prevention training programs [32,40,44]. The entire program was created to limit the equipment needed making it more accessible to amateur players. Single-leg dynamic exercises were used for balance training, strength exercises used resistance power bands, and plyometric exercises predominantly consisted of single-leg jumps (Table 1). The familiarization with the KneeRugbyWoman program was led by a certified coach and performed two weeks before the training intervention started. During the familiarization session, written instructions, as well as videos of the correct technique, were presented to players and coaches. Four levels of exercise difficulty were created for workload individualization. The initial level of exercise difficulty for each player was determined during the familiarization session. The difficulty of the exercise was increased whenever the exercise was performed with a good technique, with the coach controlling the players' progression through the training levels. The rest period between exercises was defined as half of the time of the previous exercise.

Table 1. KneeRugbyWomen program.

Exercise Type	Duration	1st Level	2nd Level	3rd Level	4th Level
Balance	30 s each	Single-leg high-knee balance	Single-leg balance forward	Single-leg balance forward and backward	Single-leg Y balance (forward, backward, lateral)
	30 s each	Lunge	Lunge with trunk turning	Lunge with weight ahead	Lunge with weight ahead and trunk turning
Strength	1 min/30 s each	Supine glute bridge	Supine glute bridge with a band above the knees	Supine glute bridge on one leg 30 s one leg	Supine walking glute bridge
	30 s each	Lateral leg raises without power band	Clams without power band	Lateral leg raises with a power band	Clams with different sizes of power band
	30 s	Bodyweight squat with calf raises	Bodyweight squat with calf raises and shoulder flexion	Bodyweight squat with calf raises with a band above the knees	Bodyweight squat with calf raises with a band above the knees and shoulder flexion
Plyometrics	30 s	Forward and backward double-leg jumps			
	30 s	Lateral single-leg jumps: from left to right (jump to the right)			
	30 s	Lateral single-leg jumps with rotation			
	30 s	Lateral single-leg cross jumps: from left to right (jump to the left)			
	15 s each	Forward and backward single-leg jumps			

2.2.5. Statistical Analysis

The normality of the data distribution was assessed using the Kolmogorov-Smirnov test with the significance level set at $\alpha = 0.05$. The data were not normally distributed; therefore, nonparametric statistical methods were used. Medians and interquartile ranges were used as basic descriptive statistics. RSI, ALS, RLS, and LESS scores between pre- and post-intervention testing were compared using the Wilcoxon matched-pairs test. Comparisons between groups (EG versus CG) were performed using the Mann–Whitney U test. Because four statistical tests (2× Wilcoxon test, 2× Mann-Whitney test) were performed for each score, the Bonferroni method was used to control Type 1 statistical error. The differences between groups were demonstrated using the Hodges–Lehmann estimate of the median differences (MD) with 95% confidence intervals [lower, upper]. The significance level for each of the four tests was set at $\alpha_B = 0.05/4 = 0.0125$. The effect size was calculated using Wilcoxon's r ($r = z/\sqrt{n}$), where the z-score is gathered via the test procedure of the Wilcoxon or Mann–Whitney test, with the sample size represented by n [50]. To determine the magnitude of the effect sizes of the data, the thresholds of 0.1, 0.3 and 0.5 for small, moderate, and large effects, respectively, were used [51]. Statistical analyses were undertaken on Microsoft Excel for Microsoft 365 Apps (version 2109, Microsoft Corp, Redmond, WA, USA) and RStudio version 1.1.463 with R version 4.0.5 (R Core Team, Vienna, Austria).

3. Results

RSI was not significantly different between EG and CG at pre-intervention (MD = −0.06 [−0.27–0.17], p = 0.632, r = 0.11 [0.01–0.49]), but players in EG had significantly greater RSI compared to CG at post-intervention testing (MD = 0.21 [0.07–0.39], p = 0.007, r = 0.55 [0.21–0.78]). Post-intervention RSI significantly increased compared to pre-intervention RSI in EG but not in CG (Table 2).

Table 2. Comparison of Reactive Strength Index (RSI), Absolute Leg Stiffness (ALS), Relative Leg Stiffness (RLS) and Landing Error Scoring System (LESS) mean scores pre- and post-intervention.

Variable	Group	Median (IQR)		MD [95% CI]	*p*-Value	r-Value [95% CI]
		Pre-Intervention	*Post-Intervention*			
RSI	EG	0.58 (0.30)	0.86 (0.30) *	−0.19 [−0.31––0.03]	0.012 +	0.70 [0.27–0.88]
	CG	0.63 (0.33)	0.59 (0.19) *	0.04 [−0.07–0.14]	0.531	0.19 [0.01–0.70]
ALS (kN·m^{-1})	EG	25.98 (5.75)	23.72 (5.29)	1.58 [−0.65–3.11]	0.110	0.48 [0.07–0.89]
	CG	23.04 (4.92)	22.60 (1.34)	0.78 [−0.94–4.35]	0.339	0.29 [0.02–0.82]
RLS	EG	32.67 (7.86)	30.48 (7.69)	2.07 [−0.13–3.98]	0.052	0.57 [0.11–0.89]
	CG	27.58 (6.92)	26.92 (4.34)	1.68 [−0.22–5.76]	0.052	0.57 [0.07–0.89]
LESS (errors)	EG	5.00 (2.00) *	4.33(1.33) *	0.50 [−0.83–1.66]	0.366	0.27 [0.00–0.82]
	CG	7.33 (0.67) *	6.17(1.33) *	0.17 [−1.16–1.67]	0.906	0.05 [0.00–0.69]

EG—experimental group, CG—control group, SD—standard deviation, CI—confidence intervals, IQR—interquartile ranges, MD—Hodges–Lehmann estimate of the median differences. * Significant difference between groups according to the Mann–Whitney U test. + Significant difference within the group according to the Wilcoxon matched-pairs signed-rank test.

ALS was not significantly different between EG and CG at pre-intervention (MD = 1.51 [−2.43–5.64], p = 0.285, r = 0.22 [0.01–0.62]) or post-intervention (MD = 0.81 [−1.40–4.78], p = 0.751, r = 0.07 [0.00–0.53]) testing. Post-intervention ALS was not significantly different compared to pre-intervention ALS in EG or in CG (Table 2).

RLS was not significantly different between EG and CG at pre-intervention (MD = 3.44 [−4.33 to 8.62], p = 0.198, r = 0.27 [0.01–0.67]) or post-intervention (MD = 2.97 [−1.29–7.47], p = 0.184, r = 0.28 [0.01–0.67]) testing. Post-intervention RLS was not significantly different compared to pre-intervention RLS in EG or in CG (Table 2).

LESS scores were significantly greater compared to EG scores at pre-intervention (MD = −1.99 [−3.33––0.67] errors, p = 0.008, r = 0.55 [0.19–0.81]) and post-intervention (MD = −2.33 [−3.00––1.00] errors, p = 0.003, r = 0.60 [0.23–0.84]) testing. Post-intervention LESS scores were not significantly different compared to pre-intervention scores in EG or in CG (Table 2).

4. Discussion

To the best of our knowledge, the current study is the first experimental study focused on ACL injury prevention in female amateur rugby players. The main finding of this study was that significant effects of the KneeRugbyWomen program were found only in RSI, while leg stiffness indicators and LESS scores showed unclear results. Therefore, observed changes in knee joint neuromuscular control indicators and landing biomechanics only partly evidence the effectiveness of a short-term ACL prevention program and do not support the proposed hypothesis.

Rebound-based testing was used in the current study to assess how leg stiffness and RSI elicits pre-activation and a stretch reflex in the lower limbs, which are the fundamental prerequisite of efficient SSC behavior. In other words, higher values of both leg stiffness and RSI require efficient SSC action [16]. Therefore, they are considered relevant jump, speed, and endurance performance indicators [52–54]. Simultaneously, lower RSI values show ACL injury risk [18]. In connection with this knowledge, it seems to be reasonable to increase values of leg stiffness and RSI.

4.1. Changes in Reactive Strength Index

In the current study, a significant main effect on RSI was found in the EG. An improvement in RSI suggests that there may be an increased ability in motor unit recruitment and, therefore, an increased tolerance to eccentric loading placed on the musculotendon unit. This improvement of neuromuscular control can reduce forces on muscles and ligaments in movements typical for rugby, such as single-leg landing or changing of direction [14]. However, the values of both groups in both measurements are low. Median RSI values of both groups (EG: 0.58, CG: 0.63) in pre-intervention testing are lower than values observed in adolescent female team sports players from the U16 age group (1.34 $\pm$ 0.24) observed in the previous study by Lehnert et al. [55]. Even with lower values than previously reported, this data may suggest that there can be improvements to the involvement of the stretch-reflex, rate-of-force development, and increased desensitization of Golgi tendon organs, all indicating the development of the neural mechanisms involved in reducing injury risk [19,56].

RSI has previously been shown to have a limited amount of common variance with leg stiffness [56]. Given the differences change of RSI and leg stiffness observed in the current study, it could be supportive of the work that the two variables are not linked. Further, it is suggested that during a maximum hopping task (as used to determine the RSI), tendon stiffness is closely connected with high levels of power output, and therefore the ability to recruit motor units will be more influential. Therefore, given maximum strength significantly modulates levels of RSI [57], we presume that the significant increases in the RSI within the current study can be attributed to increased levels of maximum strength, more precisely, relative maximum strength. We assume that during the intervention, strength was strongly stimulated due to the specific composition of the lower limb strength exercises in the KneeRugbyWomen program, with the addition of the strength required to complete the programmed plyometric and balance exercises.

4.2. Changes in Leg Stiffness

The results of the leg stiffness in the current study are comparable to the findings of only one previous study [55], in which ALS, RLS and RSI were measured in adolescent team sports players (both girls and boys) of competition age group U16. However, the population in the current study was heterogenous with a large age range (EG age: 20.05 $\pm$ 4.43 yrs., CG age: 20.04 $\pm$ 4.88 yrs.). The comparison of ALS values of our pre-intervention testing in the EG (25.98 $kN \cdot m^{-1}$) and in the CG (23.04 $kN \cdot m^{-1}$) with girls' category U16 from the above-mentioned cohort study (U16: 24.60 $\pm$ 5.00 $kN \cdot m^{-1}$) indicate lower ALS in players from EG and similar ALS in players from CG. RLS values in both groups (EG: 32.67, CG: 27.58) are lower than in female team sports players from the U16 group (34.10 $\pm$ 6.80). This may be a factor of the range of anthropometrics between the studies; in our study, players had different anthropometrics (EG height: 166.54 $\pm$ 4.46 cm, EG body mass: 64.65 $\pm$ 6.44 kg, CG height: 166.83 $\pm$ 7.30 cm, CG body mass: 69.83 $\pm$ 12.84 kg) to U16 group players (height: 166.10 $\pm$ 5.80 cm, body mass: 59.10 $\pm$ 7.90 kg) thereby influence any relative measures. Although higher values in both groups of rugby players could be expected due to leg stiffness development with age between 17–20 yrs. [23], the absence of differences could be attributed to the different performance levels [53], as elite players were observed in the study by Lehnert et al. [55], while amateur players participated in the current study. In terms of leg stiffness comparison of players from these studies, it should also be considered that both groups of rugby players in the current study were heterogenous with a large age range. Comparable results were found in a healthy population aged from 21 to 31 years [58] with ALS values of 26.30 $\pm$ 6.50 $kN \cdot m^{-1}$. However, it has to be considered that although a similar test protocol as in the current study was applied, a different measurement device was used.

The results of the current study are not supportive of a positive alteration in participants' measure of leg stiffness. The lack of change indicates no positive involvement in muscle-tendon unit activation and, consequently, no change in its ability to resist deformation originating during an SSC [22]. It has previously been determined that the variance in leg stiffness (~97%) is a product of contributions from the pre-activation of musculature and the stretch-reflex response of the extensor muscles in the lower limb [59]. Therefore, it is expected that any alterations to leg stiffness in our group after the intervention period may not suggest improvements to these control mechanisms. Comprising stiffness regulation around all the lower limb joints, the results do not point out the improvements in control of multi-joint movement during SSC exercise, lesser probability of excessive load of the knee passive structures as the ACL, and decreased ACL injury risk during rugby-specific movements in players [60].

4.3. Changes in the Landing Error Scoring System

The LESS is a clinical assessment tool that is often used in research to explore the effectiveness of injury prevention programs on the presence of landing movement "errors" that have been linked to non-contact ACL injury [45,46,61,62]. In our study, there were significant differences between EG and CG pre- and post-intervention scores (p = 0.008 and 0.003, respectively). The median pre-intervention LESS scores of the EG (5.00 errors) are similar to typical LESS scores of young female healthy populations [63]. However, the pre-intervention means the LESS scores of the CG are higher (7.33 errors) compared to similar populations [63]. According to the research [48,63], the LESS scores can be influenced by age, sex, previous injury, or neuromuscular training programs. Both groups in the current study included only females, with similar mean ages (EG: 20.05 $\pm$ 4.43, CG: 20.04 $\pm$ 4.88), participating in the same sport and competition level. Only serious knee injuries were tracked over 6 months prior to testing, and previous experiences with neuromuscular training programs were not explored. It is possible that participants in the CG have experienced more knee injuries in the preceding 6 months, had suffered more injuries to other segments of the lower limb, e.g., hip and ankle, and therefore presented with greater high-risk movement patterns according to the LESS.

According to the results, the mean difference between pre- and post-intervention LESS scores was greater in the EG compared to the CG (0.50 and 0.17 errors, respectively); however, the difference between pre- and post-intervention scores was not significant in the EG nor in CG (p = 0.366 and 0.906, respectively). According to the meta-analysis [63], neuromuscular intervention training programs completed two to three times per week and lasting a minimum of six weeks improved significantly and meaningfully LESS scores by 1.2 errors ($p < 0.001$) and also were proven to reduce the ACL injury rates [64].

The KneeRugbyWoman injury prevention program explored in this study was performed two times a week for 12 weeks; however, the mean LESS scores did not significantly decrease in the EG. The most effective programs for improving LESS scores emphasized movement control, technique feedback, plyometrics, strength, agility and core stability exercises [45,62]. Similarly, the meta-analysis exploring the effect of interventional training programs on ACL injury in females highlighted the importance of plyometric and technique feedback [64]. The KneeRugbyWoman program incorporated balance, strength, and plyometric exercises in four different difficulty levels (Table 1). The athletes needed to perform the exercise with a good technique to be able to move to the next difficulty level. However, agility exercises were not included in the KneeRugbyWoman program. Moreover, the effect of the intervention program on LESS scores was explored mainly in non-contact, jumping and cutting sports such as basketball or soccer [63]. These sports differ from rugby, and therefore the LESS testing may not be ideal, given rugby is not a jump-landing sport. Lastly, the LESS screening task used for testing differs from the one suggested by Padua et al. [46]. In this study, the SL CMJ after two steps was used instead of a double-leg vertical jump from a 30-cm box as described in the original protocol [46]. A criticism of the original LESS screening task is that it is not challenging enough or reflective of common sports movements [65,66]. Therefore, we modified this task to be a more sport-specific alternative, which is common in rugby and was used for LESS testing in previous studies [48,67].

The current findings could be influenced by the level of performance, age, and gender, the total number of training sessions [14], the overall program duration [32,68], the frequency [44,69] or the quality of exercise execution, especially landing [31]. Greater efficacy in prevention has been found in high-level players compared to low-level players and older players compared to younger players [14]. Players in our study are amateur players who train only three times a week on average, which may have made the program less effective. Our short-term intervention used a frequency of twice a week, while the training program frequency is recommended at least 1.5 times per week [70]. However, in comparison, longitudinal studies [32,36,71] worked with a similar but changing frequency during the annual training cycle, e.g., three times during pre-season but only one session in the in-season. Therefore, despite meeting the frequency of sessions, is it likely that the total duration of the KneeRugbyWomen program, at approximately 4 h, was lower than most previous studies in which a positive effect was proven, with a minimum total duration of the preventive training program was 10 h [69,72]. Therefore, it would be appropriate to verify our program over a longer time frame. Regarding training program duration, the results of the current study did not support the finding that the implementation of 15–20 min post-warm-up can improve performance and reduce injury risk because of better neuromuscular control [14]. This discrepancy could be explained by the fact that although, in total, the standard warm-up (15 min) and the KneeRugbyWomen program (10 min) fulfilled the same exercise time as in the study by Faude et al. [14], to improve landing mechanics, the duration of one training session should be approximately 15–30 min in the most effective exercise program demonstrating decreases in LESS scores [45,61,62]. On the other hand, also programs lasting 7–10 min significantly improved LESS scores [73,74]. The effectiveness of a prevention program can also be impacted by the quality of exercise execution, especially in landing, as the neuromuscular control perspective of landing skills is one of the key aspects in reducing injury risk in female team sport athletes [31,39,40]. Therefore, in our intervention, we focused on correct jumping and landing techniques both before commencing the intervention and during the training sessions. Players and coaches also had written instructions and video recordings of proper techniques created by the researchers.

4.4. Limitations

Despite the current study highlighting new information in the scientific literature, the study has some limitations. First, the results of this study should only be generalized to similar groups of female athletes. Second, the KneeRugbyWomen program includes balance, plyometrics, and strength and power exercises. In athletes with an appropriate level of flexibility, the efficiency of these exercises in injury prevention has been proven [14,35,37,38]. Unfortunately, we did not record flexibility levels in our study, and this may be a covariable that could have enhanced the findings. Third, it seems that in future studies, it would be appropriate to verify the effectiveness of preventive training programs, which also encompass sport-specific skills [75,76] and agility training [40,44,77]. Nevertheless, the time demands of these programs should meet the limited time amateur rugby players can or do spend time in training. Fourth, the original LESS is a reliable and valid injury risk screening tool [30]; however, the modified screening task was used, which may affect the reliability and validity of the tool. Fifth, given the time and resource constraints, we were unable to analyze LESS data before the randomization process. As a result, the CG had significantly greater LESS scores compared to EG prior to the intervention. Previous research has shown that individuals with poor landing mechanics tend to show the most improvement with interventions [63,78]. However, our data did not reflect this trend, as no significant changes in LESS scores were observed in either CG or EG.

5. Conclusions

The results of this study provide evidence that the KneeRugbyWomen program encompassing progressive strength and plyometric training can decrease RSI as a variable that has been previously associated with non-contact ACL injuries. However, no positive effect was observed in leg stiffness and LESS score. Although this finding suggests that such short-duration interventions may not be as efficient in increasing SSC capability and landing biomechanics, the positive effects on RSI indicate improvement in the stretch-reflex contribution, and this neuromuscular control improvement can reduce forces in movements typical for rugby players.

Author Contributions: Conceptualization, M.L. and O.S.; methodology, O.S., M.L. and J.H.; investigation, O.S., M.L. and J.H.; data curation, O.S. and I.H.; writing—original draft preparation, O.S., M.L., I.H. and J.H.; visualization, O.S. and I.H.; funding acquisition, O.S. and M.L.; supervision, M.L. and J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Palacký University Olomouc under an internal grant [Grant Number IGA_FTK_2021_008].

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Physical Culture, Palacky University Olomouc, Olomouc, Czech Republic (No. 23/2021).

Informed Consent Statement: Informed consent was obtained from all subjects or their guardians (for those under 18 years old) involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical and privacy restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

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