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The SpeedCourt system in rehabilitation after reconstruction surgery of the anterior cruciate ligament (ACL)

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Abstract

Introduction This study aimed at evaluating and finding the advantages of a program with unexpected disturbances (reaction time beyond 200 ms) in the late rehabilitation (5 months) after ACL-surgery compared to current sensomotoric based concepts.

Materials and methods 50 athletic patients (14 females, 36 males, age: 32.7 ± 10.0 years) were randomized and followed either a new training with the SpeedCourt (28 athletes) or underwent a regular stabilization program (22 athletes). Subjects were assessed at baseline and after 3 weeks, i.e. six sessions in total. The comparison of evaluations (pre- and post-training) was calculated with a two-factorial (time, group) univariate analysis with parameters for flexibility, reaction time, tapping, jump force (uni- and bi-lateral) and anthropometry.

Results In between the two groups 5 out of 22 parameters (23 %) showed significant influences, i.e. highest in the lower leg dimensions 15 cm below joint-line of the operated knee joint ($\eta^2 = 0.122$), non-operated knee joint ($\eta^2 = 0.200$) and the lower leg dimensions 10 cm below joint-line of the non-operated knee joint ($\eta^2 = 0.183$). Jump height unilateral and reaction time on the surgically treated leg were also different and improved ($\eta^2 = 0.148$; $\eta^2 = 0.138$) significantly. Differences in the outcome parameters like tapping, jump height and ground reaction time between the operated and non-operated knee were remarkably reduced in the SpeedCourt intervention group.

Conclusions Interventional training programs with the SpeedCourt system seem to be advantageous in the late rehabilitation following ACL-knee surgery compared to current sensomotoric based concepts. We achieved improvements of anthropometric and functional parameters. Further studies with larger groups and longer periods of evaluation are necessary to support these data and to possibly establish a new innovative rehabilitation concept. Clinically, the demonstrated SpeedCourt system might help to determine the time "back/return to sports" for athletes more objectively and prospectively reduce the rate of ACL re-injuries.

Keywords Rehabilitation · SpeedCourt · Knee surgery · ACL reconstruction · Return to sport

Introduction

Injuries of the anterior cruciate ligament (ACL) in the knee not only create mechanical instability, but also strongly interfere with the motor function, proprioception and postural stability [1–7]. The Ruffini endings, Golgi and Pacinian corpuscles, which play a role in proprioception and secondary for postural stability, are altered after ligament detachment and impair the joint function because it leads to

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minor afferent sensory input from mechanoreceptors to the central nervous system [4, 8–17]. Studies have shown a loss in proprioception in ACL-deficient knees [4, 18, 19] and postural regulation [20–25]. Lee et al. [26] described a significant reduction on postural stability just 3 months after the injury of an ACL. These neuromuscular deficits strongly interfere patients complaints about dysfunction and instability besides additional factors like age, muscle weakness, level of activities, and previous injury to the lower extremities [27–30].

Postural stability mainly contains feedforward mechanisms, which runs subcortical and without direct control. Deficits in postural functions are known as predictors for successive injuries on the same ACL and other impairments or injuries at the lower extremities [29, 31]. Therefore, athletes with mechanically stable knee joints after ACL-reconstruction suffer on a high risk of ligament re-injuries for about 0–19 % for the ipsilateral joint or 7–24 % for the contralateral, primary uninjured knee joint [30, 32–35]. In addition, the time after surgery should not be the exclusive and single criterion to decide if the athlete is able to return to specific sports activities, even at the previous level [23, 30, 32, 33, 36–38].

Besides the mentioned impairment of the anatomical structures, the physiological question is, “how a sensoric information at which motion can be recognized?” and in addition, “how fast this often three-dimensional information can be analyzed and switched into an active muscular reaction?”. Clinically, it is desirable to use these functional chains in prevention and rehabilitation therapy. A characteristic for an injury risk situation are ballistic influences of force, where only very short time intervals are available to generate muscular contractures to protect and avoid new stress. Taube et al. [39] first described experimentally that delayed muscle reactions above 200 ms (long latency response, LLR) initiated after postural balance impulse contributed to corticospinal control. So far, unconscious damage control happens in dimensions around 50 ms as early latency response (ELR) [39]. Rehabilitation programs usually work with reaction times above 350 ms, so patients and athletes might adapt to slow motion responses for physical stress or disturbances. The ability to answer critical situations with fast and direct functional mechanism is reduced [40]. Therefore, training with responses below 200 ms after stimulus seems to be more useful and advantageous. So far, Teichmann et al. [40] evaluated significant improvements in the single-leg press, stand jump, 20 m sprint and single-leg balance test in professional athletes after ACL-reconstruction surgery with a training and exposure of unexpected disturbances, which causes muscular reactions below 200 ms of time latency. The percentage of numbers “return to sport” increased and the ratio of re-injuries was reduced in this group of elite athletes [40].

Fig. 1 SpeedCourt-interactive training device, consisted with an active area for 7 × 7 m and 15 integrated and coded measure plates

It is well accepted to start sport-specific rehabilitation up to the 5th month after ACL-surgery, although it is still a scientific challenge to decide at what time the athlete fulfills the conditions to start specific training concepts [23, 30, 32, 33, 36–38, 41–45].

Another therapeutic, preventive and rehabilitative goal is the concept to deal with very short muscular reactions below 200 ms time latency.

The SpeedCourt (GlobalSpeed GmbH, Hemsbach, Germany; Fig. 1) demonstrates an interactive system for interventional therapy and training.

The concept is to train and improve explosive accelerations, position-specific changes of direction, coordinative skills and cognition for motor functions. Even life-kinetic programs (different colors combined with different tasks) are available in this SpeedCourt device.

The aim and hypothesis of our study was to prove if rehabilitation with unexpected disturbance programs (UDP), i.e. SpeedCourt training, and dealing with short latency responses below 200 ms, has a benefit compared to regular sensomotoric based concepts after arthroscopic ACL-surgery [41].

Materials and methods

Participants

50 active and sportive patients (14 females, 36 males, age: 32.7 ± 10.0 years) were randomized 5 months after surgery at the anterior cruciate ligament (ACL) and included in this interventional study.

28 patients (6 females, 22 males, age: 31.4 ± 7.48 years, body height: 1.75 ± 0.07 m, body mass: 76.3 ± 11.2 kg, body mass index 24.7 ± 2.50 kg × m^{-2}) underwent the new training with the SpeedCourt for 3 weeks, i.e. two sessions per week, six in total.

22 patients (8 females, 14 males, age: 34.4 ± 12.5 years, body height: 1.78 ± 0.08 m, body mass: 75.4 ± 11.6 kg,

body mass index 23.8 ± 2.82 kg $\times$ m^{-2}) took part in a regular coordinative and stabilizing program.

Concerning the anthropometric data, there was no significant difference between the two groups (sex: Chi-Quadrat = 1.36, $p = 0.243$; age: $\eta^2 = 0.022$; body mass: $\eta^2 = 0.002$; body height: $\eta^2 = 0.030$; body mass index: $\eta^2 = 0.029$).

Surgery

The surgical procedure was performed by two long-time experienced knee surgeons with more than 500 ACL-reconstructions per year each. A quadruple bundled Hamstring-transplant (tendon of the semitendinosus muscle) with Hybrid fixation and femoral bone-wedge technique was used to provide high pull-out strength [46].

Instruments and procedures

Both anthropometric and sport performance parameters were evaluated ahead and after the complete training, i.e.at baseline (=exam 1) and after 3 weeks (=exam 2).

For anthropometry the dimensions of the upper and lower leg were measured, conducted using metric tape 15 and 10 cm above, at 15 and 10 cm below joint-line.

The sports performance tests included the following:

- Total range of motion in flexion and extension (tROM),
- finger-ground distance,
- reaction time,
- ground contact time,
- tapping,
- jump height (uni- and bi-lateral) and
- jump width (bilateral).

Extension range of motion of the knee joint was measured in supine, flexion range of motion was assessed in abdomen down position. Knee flexibility was measured with a standard baseline goniometer. Technical accuracy was provided with 1° discrimination and a range of 180°.

The finger-ground distance was evaluated with the athlete positioned upright on a step, straight leg and maximum flexion in the hip joint.

Reaction time, ground contact time, tapping, uni-/bilateral jump height and width were determined with the SpeedCourt device (GlobalSpeed GmbH, Hemsbach, Germany; Fig. 1). Reliability, usefulness and validity of the SpeedCourt were evaluated from Düking et al. [47].

For evaluation of the jump height, athletes stood on a measuring plate, hands fixed at the pelvis. Extension and flexion of the hip and knee joint were performed individually, while the jumping leg needed to be completely stretched. The test was determined with both legs and single-leg. Tapping was evaluated (time interval 3 s) for elemental speed (Fig. 2).


Fig. 2 Evaluation of elemental speed (tapping) in the SpeedCourt system

Finally, a reaction test followed with athletes positioned in the center of the SpeedCourt area. The task was to answer an optical signal with steps aside to the right or left side. Time was measured for foot contact with the plate of interest after signal and total time of ground contact. Training with the SpeedCourt device was done with standard sports shoes equipment.

Jump width out of a stand (parameter: maximum jump width, technique: measuring tape) was assessed with arms closed behind at the back.

All tests were supervised from one examiner and senior member of the study group.

Interventions

Training on the SpeedCourt group

The SpeedCourt training consists of 5–6 exercises which last between 15 and 30 s. Every exercise was repeated thrice. The pause lengths showed inter-individual differences depending on the resilience of the patient. Generally the pause lengths were four times as long as the original exercise. The exercises comprised mostly running actions which were incidentally computer generated. Some of them were also color coded, which were matched to different tasks (yellow: jog twice around the field; blue: run to the opposite field).

Training on the control group

The stabilization training was standardized. Different unstable and uneven surfaces were incorporated (Posturomed, Slashpipe, BOSU, Airex, Kippelbrett, Pezziball, Stepper). Every exercise was completed in 30 s. A 30-s pause was allowed and then the exercise was performed with the contralateral side. During every training, 30 min consisted of the exercises for stabilization.

At the end of every training, a unit of invigoration exercises consisting of suspension was done. One exercise for the lower extremities and one for the trunk was always alternated. The effective training time was 15 min. The training (SpeedCourt and Stabilization) lasted for a duration of 3 weeks, twice a week. The second test interval was always conducted 2 days after the last unit of training.

Statistical analysis

Descriptive statistics were calculated across participants for the dependent variables (flexibility, tapping, jump height and reaction time). Differences between groups (SpeedCourt vs. stabilization) and sessions (one vs. two) were tested using a two-factorial (time, group) univariate general linear model. Differences between means (group, time and time × group effect) were considered as being statistically significant if p values were <0.5 and partial eta-squared (η^2) values were greater than 0.10. Partial eta-squared (η^2) values were provided to represent the level of clinical significance. Due to the small number of cases in each group, decisions on significance were made primarily based on η^2 values. We also tested the difference between non-operated and operated leg using a univariate general linear model.

Prior to the ANOVA, we analyzed the distribution of data using the Kolmogorov–Smirnov test. All data were distributed normally as a precondition for ANOVA.

All statistical analyses were performed using SPSS version 22.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

There were no significant interaction effects in 17 of the 21 parameters (81 %) (Tables 1, 2).

The highest (3/8 parameters) in numbers and largest interactions effects (lower leg dimensions 15 cm below the

Table 1 Comparison of anthropometric measurements obtained from the two testing examinations (exam 1 and exam 2) for both groups

Clinical parameters								
Group (n)	Exam 1	Exam 2	Group		Time		Group × time	
	Mean ± SD	Mean ± SD	p	η^2	p	η^2	p	η^2
Dimensions lower leg 10 cm below joint-line, non-operated leg (m)								
SpeedCourt (10)	0.385 ± 0.031	0.386 ± 0.033	**0.033**	**0.208**	0.849	0.002	**0.047**	**0.183**
Control (12)	0.363 ± 0.015	0.362 ± 0.014						
Dimensions lower leg 10 cm below joint-line, operated leg (m)								
SpeedCourt (10)	0.376 ± 0.032	0.379 ± 0.031	**0.039**	**0.196**	**<0.001**	**0.492**	0.284	0.057
Control (12)	0.353 ± 0.014	0.358 ± 0.011						
Dimensions lower leg 15 cm below joint-line, non-operated leg (m)								
SpeedCourt (10)	0.403 ± 0.033	0.404 ± 0.036	0.110	**0.123**	0.185	0.086	**0.037**	**0.200**
Control (12)	0.387 ± 0.017	0.383 ± 0.017						
Dimensions lower leg 15 cm below joint-line, operated leg (m)								
SpeedCourt (10)	0.392 ± 0.032	0.394 ± 0.032	0.063	**0.163**	0.881	0.001	0.111	**0.122**
Control (12)	0.373 ± 0.015	0.371 ± 0.020						
Dimensions upper leg 10 cm above joint-line, non-operated leg (m)								
SpeedCourt (24)	0.456 ± 0.027	0.460 ± 0.025	**0.045**	**0.107**	**0.024**	**0.134**	0.752	0.003
Control (14)	0.429 ± 0.054	0.432 ± 0.055						
Dimensions upper leg 10 cm above joint-line, operated leg (m)								
SpeedCourt (22)	0.443 ± 0.026	0.445 ± 0.025	**0.022**	**0.137**	**0.034**	**0.119**	0.700	0.004
Control (14)	0.414 ± 0.050	0.417 ± 0.049						
Dimensions upper leg 15 cm above joint-line, non-operated leg (m)								
SpeedCourt (24)	0.498 ± 0.028	0.504 ± 0.024	0.067	0.090	**0.001**	**0.283**	0.706	0.004
Control (14)	0.470 ± 0.063	0.477 ± 0.065						
Dimensions upper leg 15 cm above joint-line, operated leg (m)								
SpeedCourt (24)	0.487 ± 0.026	0.494 ± 0.023	**0.013**	**0.158**	**<0.001**	**0.319**	0.582	0.008
Control (14)	0.452 ± 0.060	0.458 ± 0.059						

Descriptive statistics (mean ± SD) and analysis of variance calculated for each parameter. Statistical significance was set at $p < 0.05$ and $\eta^2 > 0.10$ and marked in bold

Table 2 Comparison of sport motoric measurements obtained from the two testing examinations (exam 1 and exam 2) for both groups

Parameters of sport motoric tests								
Group (*n*)	Exam 1	Exam 2	Group		Time		Group × time	
	Mean ± SD	Mean ± SD	p	η^2	p	η^2	p	η^2
Jump height bilateral (cm)								
SpeedCourt (22)	24.5 ± 6.80	25.7 ± 7.00	0.284	0.034	0.104	0.076	0.248	0.039
Control (14)	27.5 ± 6.40	27.7 ± 6.70						
Jump height unilateral non-operated leg (cm)								
SpeedCourt (10)	15.5 ± 4.70	17.5 ± 5.10	0.857	0.001	**<0.001**	**0.465**	0.720	0.004
Control (8)	15.1 ± 3.20	17.4 ± 4.90						
Jump height unilateral operated leg (cm)								
Speedcourt (22)	11.0 ± 5.3	13.8 ± 5.2	0.792	0.002	**<0.001**	**0.530**	**0.020**	**0.148**
Control (14)	12.2 ± 2.9	13.4 ± 4.0						
Jump width bilateral (m)								
SpeedCourt (22)	1.38 ± 0.29	1.46 ± 0.25	0.199	0.045	**<0.001**	**0.349**	0.929	<0.001
Control (14)	1.49 ± 0.21	1.57 ± 0.25						
Tapping (*n*/3 s)								
SpeedCourt (22)	32 ± 2.8	34 ± 2.4	0.260	0.035	0.410	0.019	0.178	0.050
Control (14)	32 ± 2.4	31.6 ± 5.9						
Ground contact time non-operated leg (s)								
SpeedCourt (22)	0.37 ± 0.12	0.30 ± 0.11	**0.030**	**0.131**	**<0.001**	**0.551**	0.850	0.001
Control (14)	0.44 ± 0.04	0.37 ± 0.086						
Ground contact time operated leg (s)								
SpeedCourt (22)	0.33 ± 0.08	0.29 ± 0.09	0.195	0.049	**<0.001**	**0.488**	0.919	<0.001
Control (14)	0.37 ± 0.09	0.33 ± 0.08						
Reaction time non-operated leg (s)								
SpeedCourt (22)	1.43 ± 0.35	1.27 ± 0.29	0.714	0.004	**<0.001**	**0.606**	0.169	0.055
Control (14)	1.37 ± 0.12	1.26 ± 0.13						
Reaction time operated leg (s)								
SpeedCourt (22)	1.38 ± 0.33	1.26 ± 0.31	0.673	0.005	**<0.001**	**0.392**	**0.025**	**0.138**
Control (14)	1.38 ± 0.11	1.33 ± 0.08						
Finger-ground distance (cm)								
SpeedCourt (16)	−2.5 ± 8.9	−4.8 ± 10.5	0.205	0.057	**0.007**	**0.234**	0.435	0.022
Control (14)	3.3 ± 13.0	−0.6 ± 10.9						
Extension knee joint non-operated leg (°)								
SpeedCourt (24)	−0.3 ± 1.1	−0.3 ± 0.8	0.077	0.084	1.000	<0.001	1.000	<0.001
Control (14)	−1.1 ± 1.9	−1.1 ± 1.9						
Extension knee joint operated leg (°)								
SpeedCourt (24)	1.0 ± 1.6	0.3 ± 1.1	**0.007**	**0.185**	0.245	0.037	0.245	0.037
Control (14)	0 ± 0	0 ± 0						
Flexion knee joint non-operated leg (°)								
SpeedCourt (24)	127.8 ± 7.8	127.0 ± 7.8	0.632	0.006	0.491	0.013	0.626	0.007
Control (14)	128.7 ± 6.3	128.6 ± 9.2						
Flexion knee joint operated leg (°)								
SpeedCourt (24)	124.8 ± 8.0	127.5 ± 8.9	0.743	0.003	**0.003**	**0.220**	0.493	0.013
Control (14)	126.1 ± 5.8	127.9 ± 6.7						

Descriptive statistics (mean ± SD) and analysis of variance calculated for each parameter. Statistical significance was set at $p < 0.05$ and $\eta^2 > 0.10$ and marked in bold

Table 3 Comparison of both groups concerning differences (non-operated leg vs. operated leg) for the bilateral anthropometric and sport motoric parameters

Group (*n*)	Exam 1	Exam 2	Group		Time		Group × time	
	Mean ± SD	Mean ± SD	p	η^2	p	η^2	p	η^2
Dimensions lower leg 10 cm below knee joint-line (m)								
SpeedCourt (10)	0.009 ± 0.006	0.007 ± 0.009	0.513	0.022	**0.001**	**0.455**	0.060	**0.166**
Control (12)	0.009 ± 0.006	0.003 ± 0.005						
Dimensions lower leg 15 cm below knee joint-line (m)								
SpeedCourt (10)	0.011 ± 0.004	0.010 ± 0.008	0.190	0.084	0.287	0.057	0.644	0.011
Control (12)	0.014 ± 0.006	0.012 ± 0.004						
Dimensions upper leg 10 cm above knee joint-line (m)								
SpeedCourt (24)	0.013 ± 0.013	0.014 ± 0.013	0.609	0.007	0.866	0.001	0.537	0.011
Control (14)	0.016 ± 0.008	0.015 ± 0.010						
Dimensions upper leg 15 cm above knee joint-line (m)								
SpeedCourt (24)	0.012 ± 0.008	0.010 ± 0.008	**0.028**	**0.127**	0.930	0.000	0.258	0.035
Control (14)	0.018 ± 0.014	0.019 ± 0.015						
Jump height (cm)								
SpeedCourt (22)	4.56 ± 3.21	3.66 ± 2.23	0.022	0.137	0.922	0.000	**0.046**	**0.112**
Control (14)	2.92 ± 1.87	3.91 ± 2.03						
Ground contact time (s)								
SpeedCourt (22)	0.041 ± 0.071	0.007 ± 0.050	0.223	0.043	**0.028**	**0.134**	0.921	0.000
Control (14)	0.072 ± 0.010	0.041 ± 0.128						
Reaction time (s)								
SpeedCourt (22)	0.049 ± 0.078	0.015 ± 0.061	**<0.001**	**0.306**	**0.003**	**0.232**	0.309	0.030
Control (14)	−0.006 ± 0.06	−0.071 ± 0.08						
Knee joint extension (°)								
SpeedCourt (24)	−1.33 ± 1.74	−0.67 ± 1.27	0.762	0.003	0.279	0.032	0.279	0.032
Control (14)	−1.14 ± 1.88	−1.14 ± 1.88						
Knee joint flexion (°)								
SpeedCourt (24)	3.00 ± 4.13	−0.50 ± 4.42	0.790	0.002	**0.010**	**0.171**	0.409	0.019
Control (14)	2.57 ± 8.36	0.71 ± 4.21						

Descriptive statistics (mean ± SD of differences) calculated for each parameter and sample. Analysis of variance between differences and groups are reported. Statistical significance was set at $p < 0.05$ and $\eta^2 > 0.10$ and marked in bold

knee joint of the non-surgical knee joint: $\eta^2 = 0.200$) can be seen in the anthropometric parameters.

Significant interaction effects were observed in only 2 of the 14 parameters (14 %) of the sportmotoric parameters.

Only for the unilateral jump heights ($\eta^2 = 0.148$) and the reaction time ($\eta^2 = 0.138$) of the operated side both groups developed significant differences over the period. The movement parameters (knee extension and flexion), jump distance and elementary speed (tapping) were not influenced when compared to the interventions in between the groups.

By comparing the bilateral parameters and the two intervention groups on the basis of the difference between the operated and non-operated leg, two interaction effects could be established (Table 3).

The largest interaction effect was calculated for the lower leg dimensions 10 cm below the knee joint-line ($\eta^2 = 0.166$). Based on the lower leg dimensions measured in the SpeedCourt group (range 0.376–0.386 m), values were greater at both test intervals compared to the control group (range 0.353–0.363 m). The difference between the non-operated and operated leg was decreased primarily in the control group (0.009 vs. 0.003 m), while it remained unchanged in the SpeedCourt group (0.009 vs. 0.007 m). The second interaction effect was found for jump height ($\eta^2 = 0.112$).

In addition significant time effects were observed in the parameters of the lower leg dimensions: 10 cm below the knee joint line ($\eta^2 = 0.455$), ground contact time ($\eta^2 = 0.134$), reaction time ($\eta^2 = 0.232$) and knee joint flexion ($\eta^2 = 0.171$).

Group effects were calculated based on the following parameters of lower leg dimensions: 15 cm below the knee joint-line ($\eta^2 = 0.127$) and the reaction time ($\eta^2 = 0.306$).

According to them, the reaction time of the operated leg before and after the training period was lesser in the SpeedCourt group when compared to the non-operated leg. The opposite effect was found in the control group.

Distinct and significant reduction was measured in the differences between the operated and non-operated leg in the sportmotoric outcomes (e.g., ground contact time, jump height, reaction time) for the SpeedCourt group. The contact times are exemplarily mentioned, where the difference between the first test interval (0.041 s) and the second test interval (0.007 s) could almost be completely eliminated. In comparison, the control group reached only a reduction to the level of the SpeedCourt group in the first test interval during the period of the rehabilitation (0.072 vs. 0.041 s).

Discussion

The results of the present study show a significant improvement of the jump height and the reaction time of the anterior cruciate ligament replaced, surgically treated leg after six high reactive therapy units in the SpeedCourt group compared to a sensomotoric therapy intervention group. Simultaneously, a significant improvement of the anthropometric parameter of the lower leg dimensions 10–15 cm below the knee joint line was also identified. The differences between the operated and non-operated leg concerning the tapping, jump height and ground reaction time parameters were significantly reduced in the SpeedCourt group.

A successful rehabilitation for athletes after a tear of the anterior cruciate ligament is difficult in spite of numerous academic findings. The decision, from which point in time the conditions for the sport-specific training is fulfilled, is especially a challenge [23, 30, 32, 33, 36–38, 41–45]. Because of the unpredicted difficulties with a rehabilitation concept using disturbances causing reaction time under 200 ms 5 months after the surgery, a completely different approach was used in our program. High intensive influences were used, either sport-specific or with scant or less anticipated incidences. A comparison group was added in parallel, which was coincidentally selected to the individual groups.

The functional instability lies in the destruction of the receptors of the anterior cruciate ligament. The resulting proprioceptive deficit of the knee causes a reduced sensomotoric control of the knee joint musculature [13, 41–45]. An intact sensomotoric system is necessary for balance. Complex movement sport activities require a most sensitive and high regulation of the coordination in the knee joint and foot. All biomechanical perceptions have one factor in common, namely the reduction of the physiologic rolling- and sliding-movement because of a lack or insufficiency of the cruciate ligaments [47]. It is especially common for patients to display weaknesses in the complex jump forms in an exhausted state during the final phase of the rehabilitation [21, 48, 49]. This is particularly exemplified in the execution of the drop jumps with possible short ground reaction times. The inconsistency of the results and as well as the serious differences based on the side used in the single-leg performance justifies the recommendation to delay the return to competition sports. The majority of the studies report specific muscular imbalance after ACL-reconstructions of the operated leg and also, to a certain extent, in the contralateral leg as well [30]. Meanwhile, surgical procedures with autologous tendon transplantations have become the most common reconstructive operations of the ACL [50]. Operative errors in the ACL reconstruction today should, to a large extent, not occur any more [51]. Despite technical and rehabilitative advances in the ACL-surgery, many patients with a complete clinical and macroscopic mechanical stability complain for subjective discomfort. Consequently they cannot perform their daily activities or more specifically their preferred sport, like they used to before the injury [30]. The specific preparation of the training- and competition-specific requirements comes at the end of the athletes' training therapy [50, 51]. Ball sports are liable and per se cause higher stress to knee joints compared to cyclical sports (e.g., running, swimming, cycling).

The risk of a re-rupture of a surgically treated ACL is calculated up to 12 % in the first postoperative year, and then, according to the literature, it comes down to 2–8 % [52]. Fremerey et al. [53] were able to show on an animal model, that the cruciate ligaments directly participate in the dynamic stabilization of the knee joint through a ligamento-muscular reflex arc. Even just an elongation of the anterior cruciate ligament has a considerable influence on the neuromuscular regulation of the knee joint, before a mechanical dysfunction can be verified.

The reason for postoperative functional complaints of patients after an ACL reconstruction is attributed primarily to the neuromuscular deficits of the joint [4]. Consequently, a neuromuscular therapy must follow after the ACL-surgery. It has been proven that a consistent neuromuscular training achieved distinctly better results, compared to physiotherapy with emphasis on improvements in muscle strength [1]. Sport-specific tests should not be used after an ACL reconstruction before the 16th week after surgery [54, 55].

However, not every patient feels instable after an ACL tear. In the same way some patients with a mechanically proven stability after a repair still exhibit a persisting symptom which is described as a 'giving way'-symptom of the joint from a clinical point of view. This functional instability is debated as a disturbance of the complete neuromuscular feedback of the knee joint [10].

Freimert et al. [10] first proved that mechanically induced tibial translation in a standing test subject causes a complex, multi-physical reflex response of the hamstrings. He also succeeded in distinguishing the reflex response of the hamstrings as a short latency response (SLR) and a medium latency response (MLR). During the evaluation of the hamstring reflexes in a patient with an ACL rupture via EMG, the SLR of the injured leg was identical to the non-injured one. On the other hand, the MLR had a significantly longer latency on the injured side compared to the healthy leg. When comparing ACL patients with and without the ‘giving away’ symptoms, it was shown that the MLR in patients with the symptoms had a significantly higher latency [56]. The mechanical instability measured with a KT 1000 under functional conditions was the same in both groups. With this examination, Melnyk et al. [56] were able to prove that the ‘giving way’ symptom correlated with the neuromuscular performance, and not to the mechanical knee joint instability. This is consistent with the phenomenon of a subjective impression of instability after an ACL reconstruction in spite of an existing mechanical stability. Only in the subsequent MLR component of the biphasic reflex response, the hamstring tendons play a role in the neuromuscular regulation of the knee joint. Information through the afferent nerves can be additionally modulated through the gamma motor nerves of the central nervous system [57]. Dyhre-Poulsen et al. [58] proved that the ACL is involved in the direct reflex response of the ischiocrural musculature, the cruciate ligament-hamstring tendon reflex. This was proved in patients through direct electro stimulation of the ACL intraoperatively. Korsgaard et al. [14] was able to trigger and compare the hamstring reflex in ACL and PCL reconstruction subjects with the help of intraarticular electrodes. The ACL required a distinctly higher stimulus compared to the PCL, which highlighted the sensor function of the intact cruciate ligaments. Systematic surveys allocate a great importance to jump tests, ground contact time and reaction time [23, 51]. On the other hand, it cannot be concluded that strength as well as endurance capacity, which can be improved through a forced weight training, possesses an injury preventive relevance [59–64]. Based on the sportmotoric outcomes of our results in the final phase of the cruciate ligament surgery rehabilitation, it remains to be seen if these results can be replicated in further studies with larger groups.

The limiting factor in this examination was the small number of patients in both groups as well as the absence of comparable studies. This immensely impeded the discussions on the data, but at the same time reflected the unique design of the study. Besides that it should integrate the established clinical scores and assessment of the tibial translation (KT 1000) in future, to validate the new parameters and to enable discussions on its clinical relevance.

Conclusion

The SpeedCourt training appears to be more appropriate for the late rehabilitation after an ACL reconstruction compared to other sensomotoric rehabilitation programs. Substantial improvements in the anthropometric (e.g., lower leg dimensions) as well as sportmotoric outcomes (e.g., jump height, reaction time) could be demonstrated. On the basis of the sportmotoric outcomes (e.g., ground contact time, jump height, reaction time), it could be proved that the patients in the SpeedCourt group were able to considerably reduce the difference between the operated and non-operated leg.

Larger patient groups, sufficient and long intervals after surgery and further studies are necessary to support the demonstrated effects here and also to establish a new and innovative rehabilitation concept.

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Compliance with ethical standards

Conflict of interest The study has been performed without any source of support in the form of grants, financial donations or other items.

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