Injury Prevention in Youth Football Players Training Effects and Programme Implementation

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Linköping 2019

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Printed in Sweden by LiU-Tryck, Linköping, Sweden, 2019

ISBN 978-91-7685-019-0

ISSN 0345-0082

To Jörgen, Oscar and Jacob

I don't know anything about luck. Just the more I train the more luck I have
Ingemar Stenmark

CONTENTS

ABSTRACT	1
SVENSK SAMMANFATTNING.....	3
LIST OF PAPERS	5
DESCRIPTION OF CONTRIBUTION	6
ABBREVIATIONS	7
ACKNOWLEDGEMENTS	8
INTRODUCTION	10
BACKGROUND	12
Injury surveillance	12
Aetiology and mechanisms of injury	16
Development of preventive measures	21
Scientific evaluation of preventive efficacy	30
The intervention context.....	34
Effectiveness of preventive measures in the implementation context	39
RATIONALE OF THE THESIS.....	42
AIMS OF THE THESIS.....	43
METHODS	44
Context.....	45
Methodology for Studies I and IV	45
Methodology for Studies II and III.....	58
Ethical considerations	61
RESULTS	62
Effects on performance and jump-landing technique.....	62
Experiences of the <i>Knee Control</i> and <i>Knee Control+</i> programmes	67
Implementation of <i>Knee Control</i>	69
Adoption and use of <i>Knee Control</i>	71
DISCUSSION.....	74
Results of the intervention studies.....	74
The implementation of <i>Knee Control</i> in youth football	76
The potential for real-world effectiveness.....	79
Methodological considerations	80

Clinical implications.....	84
Transferability of study findings	84
Future research	85
CONCLUSIONS	87
REFERENCES	88

ABSTRACT

Background With 17–35% of all 14-year-olds in Sweden being active in football, injuries do occur, most frequently during match play. Based on knowledge of injury mechanisms and risk factors, different injury prevention exercise programmes (IPEPs) have been developed. In this thesis, the Swedish IPEP *Knee Control* was used as a model for injury preventive training.

Aim The overall aim of this thesis was to improve our understanding of the effects of the *Knee Control* injury prevention exercise programme on sports performance and jump-landing technique, as well as exploring programme implementation and coach experiences of using the programme in youth football.

Methods Studies I and IV were cluster-randomised trials focusing on the performance effects of *Knee Control*. Study I included four teams with 41 female youth football players (mean age 14). The intervention group used *Knee Control* twice weekly for 11 weeks, whereas the control group teams did their usual training. *Knee Control* includes six different exercises at four levels of difficulty and with partner exercises and is meant to be used during warm-up at every training session. Performance was tested using a battery of balance, agility, jump and sprint tests at baseline and follow-up at an indoor venue. Study IV had a similar set-up but included two different interventions: *Knee Control* and a new, further-developed version of the programme, *Knee Control+*, which were studied during an eight-week intervention involving eight youth football teams, four male, four female (mean age 14), with 77 players. Similar, but not identical, performance tests were used in Study IV, along with drop vertical jumps and tuck jump assessment to assess jump-landing technique.

Studies II and III focused on the implementation context. Study II was questionnaire based, using the RE-AIM framework covering the reach, effectiveness, adoption, implementation and maintenance of *Knee Control*. Coaches for female youth teams (n=352), one representative of the national football association and representatives of eight district football associations responded to web-based questionnaires. Data collection was performed two years after the nation-wide implementation of *Knee Control* started. Study III was a qualitative study that followed up on the results of Study II. Interviews were conducted with 20 coaches for female football teams and analysed using qualitative content analysis. The interviews focused on factors that affected the adoption and use of *Knee Control*. All 20 coaches had experience of *Knee Control*.

Results Limited positive effects were seen on jump-landing technique in girls, with the total tuck jump assessment score improving, as well as two separate criteria, the number of jumps accomplished during the 10-second test and additionally an increased knee-flexion angle upon landing from a drop vertical jump. No improvements on the performance tests were found in either Study I or Study IV. Both studies, however, suffered from low player compliance with the IPEPs and as a result low training dosage. No major differences in results were seen between *Knee Control* and *Knee Control+* in Study IV.

Study II showed that 91% of the responding coaches were familiar with *Knee Control*, they perceived the programme to be effective, 74% had started to use it, and it was fairly well maintained over time. However, only one third of the coaches used the programme every week and few used the whole programme. There were no formal policies for programme implementation and use in the district football associations and clubs. Study III showed that the coach was vital for programme use but needed social support, buy-in from players, resources and a feasible programme to facilitate programme adoption and use. When facing challenges with *Knee Control* implementation and use, the coaches did their best to work around these obstacles; for example, by modifying the programme content or dosage.

Conclusions In conclusion, limited positive effects on jump-landing technique were seen in girls, potentially affecting risk factors for injury positively. No clinically meaningful effects from *Knee Control* or *Knee Control+* were seen on performance tests as measured in the studies in either boys or girls. This may be related to the low training dosage. The high programme reach, perceived effectiveness, adoption and fairly high maintenance of *Knee Control* were positive. The modifications of programme content and/or dosage were concerning but will hopefully decrease with a more user-friendly programme.

SVENSK SAMMANFATTNING

Bakgrund I och med att 17–35% av alla 14-åringar i Sverige är aktiva inom fotboll så uppkommer en del skador, oftast i samband med matcher. Utifrån kunskap om skadesituationer och riskfaktorer för skador har olika skadeförebyggande träningsprogram utvecklats. I denna avhandling användes det svenska skadeförebyggande programmet *Knäkontroll* som modell för skadepreventiv träning.

Syfte Det övergripande syftet var att öka förståelsen för effekterna av *Knäkontroll* på prestationsförmåga och hopp-landningsteknik, programmets implementering och tränarnas erfarenheter av att använda programmet inom svensk ungdomsfotboll.

Metod Studie I och Studie IV var klusterrandomiserade studier som undersökte effekterna på prestationsförmågan av att träna *Knäkontroll*. Studie I inkluderade 41 flickfotbollsspelare (genomsnittsålder 14 år). Interventionsgruppen använde *Knäkontroll* två gånger per vecka i 11 veckor, medan kontrollgruppen tränade som vanligt. *Knäkontroll* involverar sex olika övningar på fyra svårighetsgrader och med tillhörande parövningar och ska användas vid uppvärmningen inför varje fotbollsträning. Prestationsförmågan testades inomhus med ett batteri av olika tester för balans, snabbhet, hopp- och sprintförmåga vid baslinje och uppföljning. Studie IV hade ett likartat upplägg men inkluderade två olika interventioner: *Knäkontroll* och en vidareutvecklad version av programmet, *Knäkontroll+*. Studien pågick åtta veckor i åtta fotbollslag (fyra pojk-, fyra flicklag) med 77 spelare (genomsnittsålder 14 år). Liknande test för prestationsförmåga användes som i studie I, men även drop vertical jumps och tuck jumps för att bedöma hopp-landningsteknik.

Studie II och Studie III fokuserade på implementeringskontexten, det vill säga implementeringen av *Knäkontroll* ute i fotbollslag. Studie II var en enkätstudie som med hjälp av ramverket RE-AIM (reach, effectiveness, adoption, implementation and maintenance) utvärderade implementeringen av *Knäkontroll*. Tränare för flickfotbollslag (n=352), en representant för Svenska Fotbollförbundet och representanter för åtta distriktsförbund besvarade de web-baserade enkäterna. Datainsamlingen gjordes två år efter att den nationella implementeringen av *Knäkontroll* startade. Studie III var en kvalitativ studie som fördjupade resultaten av Studie II. Intervjuer genomfördes med tjugo tränare för flick- och damfotbollslag och analyserades med kvalitativ innehållsanalys. Intervjuerna fokuserade på faktorer som påverkade tränarnas upptag och

användning av *Knäkontroll*. Alla tränare hade erfarenhet av *Knäkontroll* sedan tidigare.

Resultat Begränsad positiv effekt sågs på hopp-landningsteknik bland flickorna i studie IV, med en förbättrad totalpoäng på tuck jumps, på två kriterier i tuck jump, ökat antal hopp under testets 10 sekunder samt en ökad knäflexionsvinkel vid landning från drop vertical jumps. Ingen förbättring av prestationsförmågan sågs i Studie I eller Studie IV. I båda studierna var spelarnas närvaro på fotbollsträningar låg, vilket även gav en låg träningsdos av *Knäkontroll*. Inga större skillnader i resultat sågs mellan *Knäkontroll* och *Knäkontroll+* i Studie IV.

Studie II visade att 91% av tränarna kände till *Knäkontroll*, att tränarna upplevde att programmet var effektivt, 74% hade också börjat använda programmet och användandet bibehölls också förhållandevis väl över tid. Däremot använde endast 1/3 av tränarna programmet varje vecka och få använde hela programmet. Det saknades riktlinjer för programmets implementering och användning inom distriktsförbund och klubbar. Studie III visade att tränaren var outhärlig för programmets användning men behövde mer socialt stöd, intresse från spelarna och resurser utöver ett användarvänligt program för att underlätta det preventiva arbetet. När tränarna ställdes inför utmaningar gjorde de sitt bästa för att kringgå problemen, till exempel genom att modifiera programmets innehåll eller dosering, för att ändå kunna använda programmet.

Konklusion Sammanfattningsvis sågs begränsade positiva effekter på hopp-landningsteknik hos flickorna, vilket möjligen påverkar riskfaktorerna för skada positivt. Inga kliniskt meningsfulla effekter av *Knäkontroll* eller *Knäkontroll+* sågs på prestationstesterna hos varken pojkar eller flickor. Detta kan vara relaterat till den låga träningsdosen. *Knäkontroll*programmets stora spridning, högt skattade effektivitet, höga upptag och förhållandevis goda bibehållande var positivt. De modifieringar av programmets innehåll och/eller dosering som sågs var oroväckande men kan förhoppningsvis minska av ett mer användarvänligt program.

LIST OF PAPERS

- I. **Hanna Lindblom**, Markus Waldén, Martin Hägglund. No effect on performance tests from a neuromuscular warm-up programme in youth female football: a randomised controlled trial. *Knee Surg Sports Traumatol Arthrosc* 2012;20(10):2116-2123.
- II. **Hanna Lindblom**, Markus Waldén, Siw Carljford, Martin Hägglund. Implementation of a neuromuscular training programme in female adolescent football: 3-year follow-up study after a randomised controlled trial. *Br J Sports Med* 2014;48(19):1425-1430.
- III. **Hanna Lindblom**, Siw Carljford, Martin Hägglund. Adoption and use of an injury prevention exercise program in female football: A qualitative study among coaches. *Scand J Med Sci Sports* 2018;28(3):1295-1303.
- IV. **Hanna Lindblom**, Markus Waldén, Siw Carljford, Martin Hägglund. Limited positive effects on jump-landing technique in girls but not in boys after 8 weeks of injury prevention exercise training in youth football. *Knee Surg Sports Traumatol Arthrosc* 2019, e-published ahead of print.

Other papers by the author not included in the thesis

- V. **Hanna Lindblom**, Martin Hägglund. Hur införs skadeförebyggande program inom idrott? *Svensk idrottsmedicin* 2015(1):8-11.
- VI. **Hanna Lindblom**, Markus Waldén, Isam Atroshi, Annica Näsmark, Martin Hägglund. The Knee Control prevention programme. In: Volker Musahl, Jón Karlsson, Werner Krutsch, Bert R Mandelbaum, João Espregueira-Mendes, Pieter d'Hooghe. *Return to play in football: an evidence-based approach*, 2018, Berlin, Springer Nature.
- VII. **Hanna Lindblom**, Markus Waldén, Martin Hägglund. No performance enhancement after injury prevention training in male youth football players: a randomised trial comparing two interventions. Submitted manuscript.

DESCRIPTION OF CONTRIBUTION

Study I

Study design	Hanna Lindblom, Markus Waldén, Martin Hägglund
Data collection	Hanna Lindblom
Data analysis	Hanna Lindblom
Manuscript writing	Hanna Lindblom, Markus Waldén, Martin Hägglund
Manuscript revision	Hanna Lindblom, Markus Waldén, Martin Hägglund
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Study II

Study design	Hanna Lindblom, Markus Waldén, Siw Carlkjord, Martin Hägglund
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Data analysis	Hanna Lindblom
Manuscript writing	Hanna Lindblom
Manuscript revision	Hanna Lindblom, Markus Waldén, Siw Carlkjord, Martin Hägglund
Journal correspondence	Hanna Lindblom

Study III

Study design	Hanna Lindblom, Siw Carlkjord, Martin Hägglund
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Manuscript writing	Hanna Lindblom
Manuscript revision	Hanna Lindblom, Siw Carlkjord, Martin Hägglund
Journal correspondence	Hanna Lindblom

Study IV

Study design	Hanna Lindblom, Markus Waldén, Siw Carlkjord, Martin Hägglund
Data collection	Hanna Lindblom
Data analysis	Hanna Lindblom
Manuscript writing	Hanna Lindblom
Manuscript revision	Hanna Lindblom, Markus Waldén, Siw Carlkjord, Martin Hägglund
Journal correspondence	Hanna Lindblom

ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ACL	Anterior cruciate ligament
AE	Athlete exposure
App	Mobile application
CD	Compact disc
CI	Confidence interval
CMJ	Countermovement jump
CON	Control group
DVD	Digital versatile disc
DVJ	Drop vertical jump
FA	Football association
FIFA	Fédération Internationale de Football Association
HBM	Health belief model
INT	Intervention group
IPEP	Injury prevention exercise programme
NASD	Normalised ankle separation distance
NKSD	Normalised knee separation distance
NRS	Numerical rating scale
PEP	Prevent injuries and enhance performance
RCT	Randomised controlled trial
RE-AIM	Reach, effectiveness, adoption, implementation and maintenance
RE-AIM SSM	RE-AIM Sports Setting Matrix
ROM	Range of motion
SD	Standard deviation
SEBT	Star excursion balance test
SMS	Short message service
TJA	Tuck jump assessment
TRIPP	Translating research into injury prevention practice framework

ACKNOWLEDGEMENTS

First of all, I want to thank my main supervisor, Martin Hägglund, for good cooperation during the *Knee Control* projects, for your quick and thorough feedback covering both the small details and the overall picture at the same time. I also appreciate your organisational capacity, which makes sure nothing is forgotten or left to chance.

Next, thanks to my co-supervisors, Markus Waldén and Siw Carlford, for your quick and considerate feedback and ability to oversee studies from a sports medicine perspective (Markus) and from an implementation perspective (Siw) and adding considerate thoughts from your respective areas of expertise together making sure that nothing is missed.

I would also like to thank the project group behind the development of *Knee Control+*: Anne Fältström, Annica Näsmark, Tania Nilsson, Mariann Gajhede Knudsen, Mia Ryding-Ederö and Sofi Sonesson, together with Martin Hägglund and Markus Waldén, for all your valuable comments and help with deciding upon which exercises to include, how to describe them and taking photos of them.

Of course, all the administrators, coaches and players who have taken part in the pilot studies and Studies I–IV, should receive a special thank you for giving of your valuable time and effort in the research process. Without you, there would not have been a thesis! The same holds for the Swedish Research Council for Sport Science, which funded most of my PhD employment, as well as Region Östergötland and the Swedish Research Council for funding the studies.

Thanks to Anne Fältström and Amelia Arundale for valuable help with the planning of Study IV, Fredrik Wandus for help with the testing equipment in Studies I and IV, Fredrika Roos Enqvist, Oliver Freij and Peter Edenholt for help with the measurements in Study IV, Henrik Hedevik for your help with the statistical analyses and AnneLie Johansson for help with the questionnaires in Study II.

Additionally, I would like to thank all my colleagues: teachers, researchers and administrators at the Division of Physiotherapy for valuable discussions, input and help during the research process. I also want to give a special thought to the SWIPE-team (Sports Without Injury ProgrammE) of Ida Åkerlund, Nirmala Perera and Sofi Sonesson together with Martin and Markus, and to the Sports Medicine Research Group for fruitful discussions over the years.

At the same time as the *Knee Control* projects were accomplished, I was also engaged in a study on the effects of resistance training on hot flushes and would like to express my gratitude towards all of you involved in this study: Mats Hammar, Anna-Clara Spetz-Holm and Lotta Lindh-Åstrand, whom I met right at the start and planned the project with, but also Emilia Berin, Linda Shosholli, Åsa Rydmark-Kersley, Marie Rubér, PhD students, medical students and patients who took part along the way. You all taught me a lot about good clinical practice and performing complex clinical studies involving a massive amount of research data.

In my spare time, I have been active at Friskis&Svettis which has, directly or indirectly, given me valuable ideas for the research projects and offered possibilities for indoor testing of the teams. Hence, I would like to thank all officials and members at Friskis&Svettis Linköping, but especially Lotta Utterström, Gunilla Lindeberg and Carin Larsson.

Finally, thank you to my family: Jörgen for all our fruitful discussions during the research process. No one has heard as much about the research projects as you have. I really appreciate your input. Oscar and Jacob for making sure that I take time off from the research, and to my mother, Mona, for taking care of the children when needed.

INTRODUCTION

Being active in sports during adolescence is important for optimal development of physical functions and from a health-promotion perspective^{44, 136, 151}. Football (soccer) is the most popular sport worldwide, with nearly 300 million participants in 2006 according to FIFA (Fédération Internationale de Football Association)³⁵. In FIFA's report, the number of registered players had increased, among female players by 54% and in male players by 21%, between 2000 and 2006. In Sweden, there were around 360 000 registered active football players above 15 years of age in 2017¹⁶⁵. Among all 14-year-old boys in Sweden, 35% played football and among girls the corresponding figure was 17%¹⁶⁵.

Injuries in sports are, however, common, especially among youths, where the rate of injuries needing acute care is high¹⁶⁹. In youth football, acute injuries to the lower extremities are the most common injuries, with muscle/tendon strains, joint/ligament sprains and contusions dominating the injury panorama^{33, 157}. Overuse injuries, due to frequent loading, are also seen in youths participating in sports²³. Sports injuries may lead to absence from sport¹⁵⁷, heightened risk of re-injury⁸³ and fear of re-injury¹²¹. Hence, there is good reason to try and prevent these injuries.

The Translating research into injury prevention practice (TRIPP) model³⁶ describes six steps for prevention research within sports medicine, starting with studies on injury epidemiology (step 1), followed by research on aetiology and injury mechanisms (step 2), the development of preventive measures (step 3), scientific evaluation of the preventive efficacy in ideal conditions (step 4), studies of the intervention context (step 5) and finally studies of the effectiveness of the preventive measures in a real-world context (step 6) (Figure 1). This model builds on the four-step sequence of prevention originally presented by van Mechelen¹⁷², but with further consideration of the implementation context to ascertain that the effects seen in step 4 are transferable to real-world contexts, outside of a highly structured, randomised controlled trial (RCT)³⁶.

Figure 1. The six steps of the TRIPP model – Translating research into injury prevention practice that describes sports medical research in injury prevention (modified from Finch³⁶).

This thesis uses the injury prevention exercise programme (IPEP) *Knee Control* as a model for the prevention of lower extremity injuries in youth football, and builds upon steps 3 and 5 of the TRIPP model. The TRIPP model will hereafter be used as a structure for the background. The background will focus primarily on injuries in youth football and on preventing injuries using team-based IPEPs in this context.

BACKGROUND

Injury surveillance

Studies of the injury epidemiology in a particular sport is the first step in the TRIPP model. To be able to compare different studies, consistent use of injury definitions is important. An injury in football has been defined as:

Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time-loss from football activities⁴²

Injuries can also be described based on whether medical attention is needed (medical-attention injury) or whether the injury causes any time-loss from sport (time-loss injury)⁴². Injuries should be described based on their location, type, body side and mechanism of injury (traumatic/acute or overuse)⁴². Additionally, injury severity needs to be considered. Van Mechelen et al.¹⁷² listed six criteria that are important to consider regarding injury severity: 1) the nature of the injury, 2) the duration and nature of the treatment, 3) time-loss from sport, 4) time-loss from work, 5) permanent damage and 6) costs. Injury severity has also been defined as:

The number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection⁴²

Injury incidence should preferably be described as the number of injuries per 1000 player-hours (h) rather than the number of injuries per athlete-exposure (AE), since the duration of the latter may vary⁴². The prevalence of injuries has only been described in a few studies and one study calculated the weekly prevalence of overuse injuries as the number of players reporting a problem divided by the total number of players in the same study week⁸⁷. The overall injury rates in children's and youth football varies from two to seven injuries per 1000 hours of football in different studies, with higher injury rates during matches than during training as the players grow older³³, (also see Table 1). A study by Clausen et al.¹⁷, however, found considerably higher overall injury incidence (acute and overuse) of 15.3/1000 h, which may be related to different data collection methods. The most common injury types in children's and youth football are muscle/tendon strains, joint/ligament sprains and contusions³³. Between 60–90% of all injuries were classified as traumatic and 40–60% as contact injuries in the included studies³³. From the age of 14 upwards injury

characteristics were similar to those in adult players. Younger players had more fractures and injuries to the upper body, whereas muscle/tendon strains and joint/ligament sprains were less common than in players over 14³³. During a 20-week-duration study of children's football (mean age 12 years), almost 50% of all players reported overuse problems at least once during the study, and 31% reported a substantial overuse problem (leading to moderate or severe training volume or performance reductions) with a mean duration of almost four weeks⁸⁷. A study of female youth football showed a rate of lower extremity overuse injuries of 1.9 per 1000 hours, with knee injuries being the most prevalent¹²⁸. No similar study has been found for male youth football players, and overall few studies report on overuse injuries (Table 2).

Anterior cruciate ligament (ACL) injury has received a lot of attention due to its potentially severe consequences regarding return-to-sport rates, re-injuries and osteoarthritis development^{6, 16, 73, 126}, even though it only represents about 5% of all time-loss injuries in football regardless of sex or playing level¹⁷⁵. When comparing different sports, the ACL incidence rates were highest in football among girls^{51, 159} and in lacrosse and American football in boys^{51, 159}. Since football is the most popular sport in Sweden, most ACL injuries registered in the Swedish national anterior cruciate ligament register result from playing football⁴.

Table 1. Acute injury incidence in youth football players

Reference	Population	Registration method	Acute injuries
Clausen et al. ¹⁷ Denmark	438 girls (15–18 years)	SMS-based player registration. Telephone interviews with injured players	Acute time-loss injuries: 6.2/1000 h, 19.6/1000 match h, 2.3/1000 training h Knee (16%) and ankle (17%) were the most common regions suffering acute time-loss injuries
Emery et al. ³¹ Canada*	364 boys and girls (13–18 years)	Study therapist registration	Acute injuries 3.1/1000 h Lower-extremity injuries 2.5/1000 h Knee sprains 0.3/1000 h
Gilchrist et al. ⁴⁷ USA*	852 collegiate females, division I (mean age 20)	Coach and athletic trainer registration	All knee injuries: 1.1/1000 AEs ACL injuries: 0.3/1000 AEs
LaBella et al. ⁸⁴ USA*	370 female high school football and basketball players (mean age 16)	Research assistant registration	Acute onset injuries 1.6/1000 AEs ACL sprains 0.26/1000 AEs
Owoeye et al. ¹³¹ Nigeria*	204 boys (mean age 17)	Physiotherapist registration	All time-loss injuries: 1.5/1000 h, 20.3/1000 match h, 0.4/1000 training h. Acute injuries 1.3/1000 h
Rössler et al. ¹⁴⁸ Switzerland, Czech Republic, Germany, Holland*	1829 boys and girls (n=171 girls) (mean age 10)	Team contact person registration	0.4 contusions/1000 h 0.3 joint/ligament injuries/1000 h 0.3 muscle injuries/1000 h
Silvers-Graneli et al. ¹⁵⁴ USA*	850 male collegiate division I–II (mean age 21)	Athletic trainer registration	Total injury incidence rate (any physical complaint) 15/1000 AEs Ankle injuries 2.6/1000 AEs, knee injuries 2.3/1000 AEs
Soligard et al. ¹⁵⁷ Norway*	837 girls (mean age 15)	Coach registration	Sprains 1.7/1000 h Strains 0.6/1000 h Contusions 0.7/1000 h
Stanley et al. ¹⁵⁹ USA	Players at high schools and colleges during 5 academic years	Athletic trainer registration	0.8 / 2.2 ACL injuries/10 000 AEs in male / female football players Relative risk in girls versus boys 2.8
Steffen et al. ¹⁶⁰ Norway*	947 girls (mean age 15.4)	Study physiotherapist registration	Acute injuries: 3.2/1000 h, 7.6/1000 match h, 1.3/1000 training h Lower body injuries: 2.8/1000 h Sprains 1.3/1000 h, strains 0.6/1000 h
Steffen et al. ¹⁶¹ Canada*	135 girls (13–18 years)	Team designate registration	All injuries (medical attention and time-loss): 6.0/1000 h Lower extremity injuries: 5.0/1000 h
Häggglund and Waldén ⁶⁹ Sweden	4556 girls (12–17 years)	Coach registration	Acute knee injuries 0.35/1000 h, 1.1/1000 match h. ACL injuries 0.08/1000 h, 0.2/1000 match h, 0.07/1000 training h.

*Intervention studies, injury rates are presented for the control groups. Abbreviations: ACL, anterior cruciate ligament; AE, athlete exposure; CL, cruciate ligament; SMS, short message service

Table 2. Overuse injury incidence and prevalence in youth football players

Reference	Population	Registration method	Overuse injuries
Clausen et al. ¹⁷ Denmark	438 girls (15–18 years)	SMS-based player registration. Telephone interviews with injured players	Overuse time-loss injuries: 3.5/1000 h, 55% were new injuries
Leppänen et al. ⁸⁷ Finland	733 boys and girls (9–14 years)	SMS-based player registration. Telephone interviews with injured players	47% had at least one episode of an overuse problem, 31% a substantial overuse problem. Highest prevalence of overuse injury in the knee. Average injury incidence 172/100 person-years. Higher average weekly prevalence in girls than boys (17 versus 12%). Boys to a greater extent suffered from heel overuse problems, whereas girls suffered from knee overuse injuries most often
O’Kane et al. ¹²⁸ USA	351 girls (12–15 years)	Parent registration by weekly email survey. Telephone interviews with injured players	1.9 lower extremity overuse injuries per 1000 h. Repeat overuse injuries: 3.4/1000 h. Knee injury was most common: 0.9/1000 h.
Owoeye et al. ¹³¹ Nigeria*	204 boys (mean age 17)	Physiotherapist registration	0.2/1000 h
Rössler et al. ¹⁴⁸ Switzerland, Czech Republic, Germany, Holland*	1829 boys and girls (4.4% girls), mean age 10.	Team contact person registration	0.16/1000 h
Steffen et al. ¹⁶⁰ Norway*	947 girls (mean age 15)	Study physiotherapist registration	0.5/1000 h

*Intervention studies, injury rates are presented for the control groups. Abbreviations: SMS, short message service

Sex-related differences in injury rates

Taking into account all injuries in football requiring acute medical care, the incidence rates differ between the sexes, with more knee and ankle injuries among girls¹⁶⁹. There was also a dominance of joint and ligament injuries in girls, whereas fractures were more common in boys¹⁶⁹.

In a systematic review, 0.15 ACL injuries per 1000 athlete exposures (AEs) were seen in female football players, whereas the corresponding figure in male football players was 0.04/1000 AEs, rendering a relative risk of 3.7 in females versus males⁵¹. In a Swedish context a register-based study showed a rate of cruciate ligament injuries of 4.8/1000 player-years in females and 2.7/1000 in males, i.e. a relative risk of 1.8 in females versus males¹⁸⁷. A meta-analysis showed a 2.2-fold

higher risk of ACL injury in female football players¹⁰⁷, another study that the risk was heightened 2–3 times in female football players compared to male players¹⁷⁵. When exposure is considered, there seems to be a higher ACL injury rate during match play among female football players compared to males, whereas no difference between sexes is seen during training¹⁷⁵. However, one must bear in mind that male players have greater exposure than female players, with more time spent on training sessions and games and, hence, the actual number of newly injured players does not differ between sexes¹⁰⁷. The female players are also younger when suffering ACL injuries, with a mean age of 20 years in female versus 24 years in male players¹⁸⁷. A Swedish register study showed a high-risk period for cruciate ligament injuries between 11 and 20 years of age among females, whereas the male injury incidence was higher between 21–30 years of age¹¹⁸. ACL injuries are uncommon in children, but from the age of 12 the ACL injury rate starts to increase, especially in girls, and peaks during adolescence in females^{152, 175}.

Consequences of an injury

When looking at the whole injury panorama, most time-loss injuries in youth result in absence from football play of less than one week, whereas only 10–15% are defined as severe, with an absence of more than 28 days³³. There is a risk of recurrent injuries¹⁷ and players may avoid or delay return to sport due to fear of re-injury¹²¹.

Many overuse injuries probably go undetected and untreated in female youth football players and only half of them have their injury examined by parents, coaches or a medical provider¹²⁸. Female youth football players with overuse injuries limited their participation due to pain, but also out of fear of making the condition worse, due to weakness or the joint giving way¹²⁸. Knee overuse problems have been shown to affect self-reported performance and participation rates to the greatest extent in youth football players⁸⁷.

Aetiology and mechanisms of injury

Studies of injury aetiology and injury mechanisms are the second step in the TRIPP model.

Injury mechanisms

It is important to understand injury mechanisms when developing preventive measures⁹. Out of all injuries, 40–60% in youth football are due to contact with another player or an object³³. Few studies in children's and youth football, however, describe the injury circumstances in more detail than by separating between traumatic and overuse injuries, or contact and non-contact injuries³³.

The ACL injury mechanisms in youth football have not been described. Studies from elite football and handball show that the majority of ACL injuries are non-contact and occur without contact with an opponent¹⁷⁷, usually during plant-and-cut with the foot fixed to the floor and positioned outside the knee, or during one-legged landing from a jump^{129, 177}. In the injury situations, the knee flexion angle was always less than 20° and knee valgus, but not valgus collapse, was often seen¹⁷⁷. A valgus collapse has been described as a situation in which the knee collapses medially in excessive valgus and/or rotation of the tibia and hip⁸¹. No studies regarding injury situations in female football have been found. With regard to serious knee injuries, the injury mechanisms are probably comparable across different sports¹⁵⁷. In female basketball and handball, ACL injuries occurred in association with valgus collapse and tibial rotation shortly after initial contact during cutting or one-legged landing^{79, 129}. When comparing injury patterns between male and female basketball players valgus collapse, a combination of hip internal rotation, knee valgus and external rotation of the tibia, was more often seen in female players at the time of injury⁸¹.

Risk factors for injury

It is important to identify influential risk factors for injury in order to be able to prevent injuries¹⁷². Risk factors may be divided into internal and external risk factors^{9, 106, 179}. Internal risk factors may be age, sex and body composition, while external factors such as shoe-surface friction may also modify the injury risk. In addition, an inciting event is needed to sustain an injury⁹. Studies also show that previous injury may be a risk factor for new injury, with a three-fold increased risk of knee injury among female youth players who have a previous knee injury¹⁸.

Most risk factor studies in football focus on acute injuries or study both acute and overuse injuries within the same study, whereas knowledge about risk factors for overuse injuries are lacking, especially in children and youths^{23, 128}. Overuse injuries are believed to occur as a result of repetitive submaximal loading coupled with inadequate rest to allow for structural adaptation to better withstand the load, or as a result of excessive stress on the tissues²³. The risk of overuse injuries seems to increase during the pubertal growth spurt, as the tissues are not as able to withstand high forces while growing at a fast rate²³. One study showed an increased risk of developing knee overuse injuries in football players presenting with valgus of the knees¹²⁸. The risk of overuse knee injuries was reduced with stronger hamstrings, quadriceps, hip flexor and hip external rotation muscles¹²⁸. Other commonly cited intrinsic risk factors for overuse injuries are growth-related, related to physical and psychological development, menstrual dysfunction and anatomical factors, in addition to previous injury²³.

Regarding ACL injuries, the evidence points to multifactorial risk factors: neuromuscular, biomechanical, anatomical, genetic, hormonal and other

mechanisms that interact towards injury¹⁵³. However, thus far, most studies have studied isolated risk factors, making it difficult to fully understand the nature of the ACL injury¹⁵³. One study of female youth football found that players who suffered from an ACL injury had a higher mean age, mean weight, mean BMI and someone with an ACL injury within the family compared to uninjured players⁶⁹. Players over 15 years had an almost two-fold increase in the rate of acute knee injuries compared to younger players⁶⁹.

Impaired neuromuscular control as a risk factor for injury

Some internal risk factors are modifiable and may be affected by interventions, whereas others are non-modifiable. Hereafter, risk factors with the potential to be affected by training interventions will be described, all related to neuromuscular control. There are different definitions of neuromuscular control (also called sensorimotor control):

the intricate balance of adequate strength and mobility, kinesthetic awareness, efficient joint mechanics, and a sufficiently adaptive motor control system²⁴

the unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability¹⁴⁴

Neuromuscular control is believed to result from complex interactions between the nervous system (somatosensory feedback from peripheral receptors, visual receptors and the vestibular system) and the musculoskeletal system¹⁷⁸. Dynamic stability (or functional stability) has been defined as:

the ability of the joint to remain stable during physical activity²

Dynamic knee stability is accomplished by the geometry of the articular surfaces, the soft tissue restraints and the loads applied to the joint from weight-bearing and muscle action¹⁷⁸. These active, muscular and passive joint strategies are believed to work in synergy to obtain stability¹⁰⁹. By coordinated muscle activity, such as co-contraction, joint stability seems to increase while the strain in the ligaments decreases¹⁷⁸. With increased dynamic stability, the load on the joints is believed to decrease or become more evenly distributed².

When neuromuscular imbalances occur, the joint is subjected to increased load due to deviant muscle strength or activation patterns¹⁰⁹. With neuromuscular imbalances, the demands on the passive stabilisers increase, which may affect the risk of injury and contribute to ACL injuries¹⁰⁹. A load that is greater than the stability provided by the stabilising muscles, ligaments and joint compressive forces from weight-bearing will result in an injury¹⁷⁸. The forces to which the individual is exposed can be reduced in two ways: 1) reduce the size of the loads by changing posture or technique, 2) increase the strength and/or activation of

muscles that cross the joint⁹³. In a study by Hewett et al.⁶⁰, female football, basketball and volleyball players who later sustained an injury showed altered neuromuscular control with increases in knee valgus angles and moments during drop vertical jumps⁶⁰. Additionally, low knee-flexion angles on landing increased the risk of injury⁶⁰. Other studies in different sports have failed to replicate these results^{82, 86}.

One study examined muscle activation patterns as an isolated risk factor for non-contact ACL injury¹⁸⁵ and showed reduced EMG pre-activity of the semitendinosus muscle and increased pre-activity of the vastus lateralis muscle before side-cutting in female handball and football players who later had a non-contact ACL injury compared to players who remained uninjured¹⁸⁵. This study underlines the importance of medial hamstring muscle activation for the prevention of ACL injuries¹⁴.

Different types of studies (cadaveric, experimental) have shown that activation or simulated activation of the quadriceps muscle between 5–45° of knee flexion increases the strain on the ACL, whereas activation of the hamstring muscle may reduce the strain above 10° of knee flexion^{38, 99, 143} and externally rotate and posteriorly translate the tibia during flexion⁹⁵. When landing from jumps with low knee-flexion angles, the ACL was subjected to loading related to contact forces and anterior patellar tendon pull, while the ground-reaction force and forces within the hamstring muscle reduced the tension in the ACL⁷⁴. When the knee-flexion angle upon landing was higher, the patellar tendon pull was reduced, while the hamstring muscles created a larger posterior pull on the tibia, reducing the loading on the ACL⁷⁴. The greatest strain on the ACL was seen when combining an anterior tibial force and internal rotation of the tibia near full extension or anterior tibial force plus valgus loading beyond 10° of knee flexion⁹⁸. It is believed that combined loading of the ACL in multiple planes is what strains it the most, and this is believed to be the mechanism behind ACL injuries¹³⁹.

The pubertal transition

The pubertal transition is an important time for learning new skills and performance development in football players¹⁴⁶. Few pre-pubertal athletes show probability of high knee abduction moments associated with a high risk of injury compared to post-pubertal athletes^{25, 61}. Hence, in a population of growing individuals, age should be taken into account when considering risk factors for injury^{25, 61}. Additionally, growth-related injuries are also prevalent during the pubertal transition, before skeletal maturity has been achieved³³.

During maturation, both boys and girls go through rapid growth, which leads to longer levers and a potential increase in muscle torque¹³⁸. Neuromuscular imbalances may increase during this period if the neuromuscular system does not adapt to the increased length of levers and greater body mass¹³⁸. During the pubertal and post-pubertal stages, boys go through a neuromuscular spurt and

improve their neuromuscular control, whereas no similar change is seen in girls¹³⁸. Additionally, differences in landing techniques emerged, with girls displaying divergent biomechanical profiles with increasing age, especially in the frontal plane^{25, 63}, whereas boys maintain a landing strategy primarily within the sagittal plane²⁵. During the later stages of maturation, girls land with less knee flexion at initial contact and have lower quadriceps strength compared to pre-pubertal active girls and postpubertal boys, and also show a higher degree of hip frontal displacement²⁵. A study by Fort-Vanmeerhaeghe et al.⁴¹ using the tuck jump assessment to subjectively assess jump-landing technique, however, showed an overall improvement with fewer landing deficits as both girls and boys passed through puberty. However, no improvement in knee valgus at landing was seen over time in girls, whereas boys improved their performance⁴¹.

Sex-related differences in ACL injury risk

Differences in ACL injury risk between boys and girls are believed to be related to differences in anatomical, hormonal and neuromuscular factors⁵⁴. From now on, only neuromuscular differences between boys and girls will be described, since these are the ones that can be most easily affected by training interventions.

In a meta-analysis, it was shown that girls had greater knee valgus during adolescence compared to boys and that the girls' knee valgus angles increased during maturation⁶³. No differences were seen, however, between vertical ground-reaction forces or knee flexion angles in boys versus girls⁶³. In kinematic analyses, differences in muscle activation patterns and neuromuscular control have been shown between elite youth female and male players, which is believed to contribute to the increased ACL injury risk in females⁸⁵.

Female handball players showed less pre-activation of the semitendinosus and biceps femoris than male players, while pre-activation of the quadriceps muscles did not differ prior to ground contact during side-cutting¹³. This was interpreted as a sign that female players have a different neuromuscular strategy than male players in ACL injury risk situations¹³. In addition to different muscle activation patterns, with less activation of the hamstring muscles and more activation of the quadriceps muscles, female recreational athletes within volleyball, football and basketball also land with higher knee valgus angles and smaller knee flexion angles⁹⁶.

Development of preventive measures

Injuries may be prevented by various means: by using protective equipment, by constituting rules and regulations to protect the athletes and by doing preventive training⁷⁷. It must also be acknowledged that female youth players with low or irregular attendance at football practice are at high risk of injury and that the risk may potentially be reduced by simply attending regularly¹⁷. However, this section focuses on the development of injury prevention exercise programmes.

With our present knowledge about injury patterns and risk factors, neuromuscular IPEPs have been developed with the aim of preventing injuries, which is step 3 of the TRIPP model. Most IPEPs are short warm-up programmes that aim to prevent lower extremity injuries in general in all members of a team in different sports. In Table 3, several IPEPs are listed. There are also some programmes, such as *Sportsmetrics*, that are much more extensive, taking around 90 minutes to complete⁵⁹. From now on focus is primarily on the shorter, multi-component programmes.

It has been suggested that IPEPs be introduced from the onset of puberty, before biomechanical and neuromuscular differences between the sexes appear, and continued throughout the pubertal transition, to counter any negative effects of maturation and reduce the risk of ACL injury^{25, 63}. It is also hypothesised that a neuromuscular spurt can be stimulated by means of neuromuscular training^{60, 138}. The overall aim of these programmes is to improve neuromuscular control and to maintain and restore function and stability¹⁴⁴.

Table 3. Injury prevention exercise programmes for youths in different team sports

Sport	Reference	Intervention	Dosage	Content
Australian football	Fortington et al. ³⁹	<i>FootyFirst</i>	20 min, 2 times/week	10 min general warm-up. Lower-limb strength and conditioning exercises. 5 levels of progression. Focus on correct technique, volume and intensity
Floorball	Pasanen et al. ¹³⁴	'Neuromuscular training programme' <i>Knee Control</i>	20–30 min. 2–3 times/week two intensive training periods. Once/week competitive season	Running technique, balance and body control, plyometrics, strengthening, stretching. Possible to choose among exercises within each part of the programme. Focus on proper technique
Football	Hägglund et al. ⁶⁷		10–15 min, preceded by 5 min running warm-up. Twice/week	6 neuromuscular exercises with focus on core stability, leg strength, balance and jump-landing technique at 4 levels and additional partner exercises for intermittent use. Focus on proper technique
	Kiani et al. ⁷⁵	<i>HarmoKnee</i>	20–25 min. Twice/week preseason, once/week regular season	5 parts: warm-up, muscle activation, balance, strength, core stability
	Mandelbaum et al. ⁹⁷	<i>PEP</i>	20 min	Focus on proper technique
	Rössler et al. ¹⁴⁷	<i>11 + Kids</i>	15 min. Twice/week	Warm-up, stretching, strengthening, plyometrics, football-specific agility drills. Focus on proper technique
	Soligard et al. ¹⁵⁷	<i>11 +</i> (combines key exercises from the 11 and PEP)	20 min. Every training session Running exercises before matches	3 parts, 7 exercises in total: spatial orientation, anticipation and attention, body stability and movement coordination, fall techniques. 3 levels. Specific attention on the body axes during exercises
	Steffen et al. ¹⁶⁰	<i>11</i>	15 min preceded by 5 min running warm-up. Every training session the first 15 sessions, thereafter once weekly	3 parts: 1) running exercises, 2) 6 exercises for strength, balance and plyometrics on 3 different levels, 3) speed running. Focus on quality of movements
Handball	Myklebust et al. ¹¹³	ACL injury prevention programme'	15 min, 3 times/week for 5–7 weeks, thereafter once/week.	10 exercises, focus on core stability, balance, dynamic stabilisation and eccentric hamstring strength Focus on proper technique Additional equipment: balance mats
Rugby	Hislop et al. ⁶²	'Movement control exercise programme'	20 min Every training session and before matches	3 parts: floor exercises, balance mat exercises, wobble-board exercises, 5 levels of progression Focus on improving awareness and knee control Balance/perturbation training, resistance training, plyometrics, sport-specific landing and cutting manoeuvres. 4 levels with progression. Focus on proper technique

Abbreviations: ACL, anterior cruciate ligament; PEP, Prevent injuries and Enhance Performance

Neuromuscular training

Neuromuscular training has no uniform definition and has also been called proprioceptive training and functional training, amongst others². Neuromuscular training has been used as a strategy to prevent ACL injuries and as a means of rehabilitation after injury². Neuromuscular training aims to address the neuromuscular imbalances that are seen in the actual population¹⁰⁹. Exercises involving multiple joints and muscle groups, usually in closed kinetic chains, are often used². Movement quality and alignment of trunk and lower extremities is central².

The main idea of lower extremity neuromuscular training is to reduce the loads on the ligaments by developing motor programmes with coordinated muscle activity and by training to perform skills in biomechanically safe ways¹⁷⁸, but also to achieve proper alignment that may potentially protect against acute and overuse injuries¹²⁸. This may be achieved by regularly challenging the static or dynamic control of the joints in order to improve neuromuscular control and joint stability¹⁷⁸.

When used in rehabilitation progression should be made individually, based on each patient's neuromuscular control and movement quality². In the IPEPs used in team sports, the neuromuscular training is usually team-based and progressed for the whole team at the same time for practical reasons^{66, 92, 147-148}. During all exercises, the quality of the movements should be emphasised². Thus, feedback is essential in neuromuscular training¹ and is emphasised in several of the IPEPs^{47, 67, 70, 157, 167}. Since exercises that are performed incorrectly may reinforce improper techniques, the coach should supervise the preventive training and give continuous feedback on proper technique to facilitate positive neuromuscular alterations¹⁰⁹.

Injury prevention exercise programme contents

Neuromuscular training may be accomplished by means of dynamic, multiplanar and sports-specific exercises that challenge the proprioceptive system¹⁰⁹ and may result in safer movement patterns⁶⁰. In addition, training to improve joint stabilisation, exercises that stimulate ligament and capsule mechanoreceptors, plyometric training that may improve reaction times and skills training to reduce external loads should be incorporated⁹³. The hamstrings and quadriceps muscles are seen as the most important to strengthen when aiming to increase varus-valgus stability of the knee⁹⁴.

The following have been described as important:

- hamstring pre-activation and strengthening¹³
- quadriceps and gluteus strengthening²⁵
- promoting knee flexion upon landing⁸⁶
- avoiding stiff landings⁸⁶
- avoiding excessive valgus of the knees⁶⁰

The majority of IPEPs are multi-component^{32, 34} and cover balance, agility and strength training^{32, 65}. Some multi-component programmes also include stretching, plyometrics, running, training of cutting and landing technique⁶⁵ and proximal control exercises⁸. Usually, several aspects of neuromuscular control are covered in the exercises, such as muscle strength, balance, coordination and proprioception, but with different emphases in different exercises¹⁻². The exercises aim to improve neuromuscular function in general⁶⁶. Whether all components of the programmes are important to achieve the preventive effect is hard to assess³².

Injury prevention exercise programmes

Different IPEPs to be used in the warm-up before practice have been developed, primarily for youths participating in team sports. All players in a team are usually targeted with IPEPs since studies have failed to find high-risk individuals for ACL injuries among players in team sports^{82, 86, 155}, or lower extremity injuries in general in female elite football players¹¹⁶ with the use of screening tests.

Universal training is also supported by cost-effectiveness analyses, further emphasising the benefits of universal training for all players, rather than screening for injuries followed by training those at high risk of injury¹⁶⁶. When all individuals in a team are targeted for injury prevention, the numbers needed-to-treat are usually large, but this is still deemed the most practical real-world solution⁶⁶. Some vital parts of IPEPs have been described by coaches: that the intervention duration is less than 20 minutes, that it can substitute for an ordinary warm-up, that coaches can access information about the exercises and have someone to demonstrate them¹⁰¹. Well-known IPEPs, intended to be used together with the warm-up before training (Table 3), have been studied in youth football. These programmes are rather similar in their set-up and exercises. In this thesis, *Knee Control* is used as an example of an IPEP.

***Knee Control* and its implementation context**

Knee Control (Knäkontroll, SISU Idrottsböcker©, Sverige, 2005) was designed by physiotherapists within the medical organisations of the Swedish Football Association (FA), the Swedish Handball Federation, the Swedish Basketball Federation and the Swedish Floorball Federation, SISU Idrottsutbildarna, the Swedish Rheumatism Association, Elitidrottscentrum Bosön, the Swedish School of Sport and Health Sciences and the insurance company Folksam, which covers all players over 15 years of age. The programme first became commercially available on a compact disc (CD) in 2005 and nationwide implementation started in 2010 (Table 4).

Knee Control is a coach-led programme that was developed to be used in football, handball, floorball and basketball, together with the warm-up before training, specifically among youths. From 2012, running warm-up exercises were added and the programme was made available for free on a mobile application/webpage. Hence, since 2012, the programme has contained a standardised running warm-up (5 minutes) and six principal exercise components (approximately 15 minutes): one-legged knee squats, pelvic lifts (for hamstring strengthening), two-legged knee squats, the bench (core strength), lunges and jump/landing. The exercises are available at four levels of difficulty and with one partner exercise per principal exercise. Progression is made, usually on a team basis, as the coach identifies improvements in the performance of the exercises. The only equipment used is a football and progression is made with longer levers or with exercises in other directions. See Hägglund et al.⁶⁷ for a full description of *Knee Control*. The Swedish FA offers courses for coaches, but none are mandatory. Since 2016, information about the *Knee Control* IPEP has been included in the curriculum in one of the first basic courses for coaches.

Table 4. Time-line for *Knee Control* and studies on the programme

Year	Programme timeline	Study timeline	References
2005	<i>Knee Control</i> programme published		
2009		RCT on the effects of <i>Knee Control</i> on acute knee injuries in female youth football	Hägglund et al. ⁶⁷ Waldén et al. ¹⁷⁶ Hägglund et al. ⁶⁸ Hägglund and Waldén ⁶⁹
2010		RCT on the effects of <i>Knee Control</i> on performance in female youth football	Lindblom et al. ⁸⁸
2012	Launch of app Running warm-up added		
2013		Study on the implementation of <i>Knee Control</i> in youth female football	Lindblom et al. ⁸⁹
2015		Qualitative study with coaches for female football teams	Lindblom et al. ⁹⁰
		Study on the national implementation and effectiveness of <i>Knee Control</i>	Åman et al. ¹⁸⁷
2016	<i>Knee Control</i> added to the coaching course curriculum		
2017	<i>Knee Control+</i> is developed <i>Knee Control</i> app published in German	Study on the performance and jump-landing technique effects of <i>Knee Control</i> and <i>Knee Control+</i> in male and female youth football RCT on the effects of <i>Knee Control</i> on injury rates in youth floorball	Lindblom et al. ⁹¹ , Lindblom et al., submitted manuscript Åkerlund et al., submitted manuscript
2018	App is replaced by website	RCT on the effects of <i>Knee Control</i> on injury rates in youth handball	Asker et al., ongoing data analysis
2019	English version of programme under way	Development of a checklist for exercise fidelity	Ljunggren et al. ⁹²

Abbreviations: App, mobile application; RCT, randomised controlled trial

Performance enhancements from injury prevention exercise programmes

Studying the performance effects of IPEPs is relevant for at least two reasons: 1) improved performance may be associated with reduced injury risks and 2) improved performance may be a key component of improving programme adherence and succeeding with real-life implementation¹⁴⁷. Sports-specific performance improvement from IPEPs may be an argument for convincing coaches and players to use the programmes on a regular basis³⁴. When studying the adaptations in neuromuscular performance from IPEPs, we may learn more about the effect mechanisms^{34, 70}. At present, the effect mechanisms of using IPEPs are not fully understood^{133, 167}. Few programmes have been shown to both improve performance and reduce the risk of injury, with the extensive *Sportsmetrics* being an exception¹²⁰.

A recent meta-analysis incorporating 14 studies on different IPEPs, predominantly in football players, showed positive performance effects favouring the intervention groups regarding balance/postural stability, strength, sprint ability and speed³⁴. The effects were only small to moderate in general, but with large positive effects for leg strength and sprint ability in boys³⁴. Overall, the effects were larger when the training volume was higher, which underlines the importance of longer training periods, higher dosage and better compliance³⁴. In another systematic review covering studies on performance improvement from preventive programmes in youth sports (all but one covering football and futsal), the greatest mean percentage improvement was seen in tests of muscle strength and coordination (+11% vs. + 6%)⁵⁶.

Studies of the *PEP (Prevent injuries and Enhance Performance programme)*, *11+*, and *11+ Kids*, programmes known to prevent injuries, have shown small positive effects on performance in children and youths of both sexes (Table 5). Most studies, however, have been conducted with male players. Positive effects in the intervention groups have been seen in agility^{137, 147, 182}, and vertical jump height^{137, 142, 147, 182}, but also balance and stability^{45, 162} and strength^{20-21, 142, 183}. However, the results are not conclusive when compared across studies, since not all studies show effects from the same tests, and some studies also showed positive effects in the control group^{45, 137, 162, 182-183}. No studies had been conducted on the performance effects of the *Knee Control* IPEP before the present research projects commenced.

Table 5. Performance effects of injury prevention exercise programmes in youth football

Reference / participants	Intervention	Dosage	Measurements	Effects
Daneshjoo et al. ^{20,21} 36 males (mean age 19)	<i>II+ / HarmoKnee</i>	20–25 min, 3 times/week, 8 weeks	Isometric and isokinetic quadriceps and hamstrings strength.	Isometric tests: Improved quadriceps strength in both INT, increased hamstrings strength only in the INT using <i>the II+</i> . Small improvements in hamstrings quadriceps ratio of the isokinetic tests in the INT using <i>the II+</i>
Gatterer et al. ⁴⁵ 16 males (mean age 10)	<i>II+</i>	30 min, twice/week, 5 weeks	Bilateral long jump, body stability	Improved body stability in INT and CON
Pomares-Noguera et al. ¹³⁷ 23 males (mean age 12)	<i>II+ Kids</i>	15 min, ≥ twice/week, 4 weeks	ROM, Y-balance test, 20 m sprint, CMJ, drop jump, horizontal jump, wall volley test, slalom dribble, Illinois agility test	INT improved in Illinois agility test, CMJ and drop jump. INT and CON improved in slalom dribble. CON improved in 20 m sprint
Reis et al. ¹⁴² 36 male futsal players (mean age 17)	<i>II+</i>	Twice/week, 12 weeks	Isokinetic quadriceps and hamstring strength, squat jump, CMJ, 5 m and 30 m sprint, agility t-test, slalom dribble, single-leg balance	Improvements in INT: quadriceps and hamstrings concentric and eccentric torque, squat jump, CMJ, sprint times, agility and slalom dribble.
Rössler et al. ¹⁴⁷ 122 players, (n=6 females) (mean age 10)	<i>II+ Kids</i>	15 min, twice/week, 10 weeks	Static balance, Y-balance test, 20 m sprint, CMJ, drop jump, bilateral long jump, Wall volley test, slalom dribble, agility run	INT improved in CMJ and deteriorated to a smaller extent during agility run compared to CON (small effect)
Steffen et al. ¹⁶² 226 females (13–18 years)	<i>II+</i> + two kinds of delivery	20 min, 2–3 times/week, 7–11 weeks	Single-leg eyes closed balance, SEBT, Single-leg triple hop, jump-over-a-bar test	Between groups differences: Supervised INT improved more in balance and SEBT performance. Jump performance decreased compared to CON. CON performed better than INTs in jump-over-a-bar test
Vescovi et al. ¹⁷⁴ 31 females (mean age INT 16, CON 17)	<i>PEP</i>	3 times/week, 12 weeks	9, 1, 18, 2 and 36.6 m sprint, CMJ, Illinois agility test, pro-agility test	Small improvements in INT from week 0–6 in sprint times, that returned to baseline values, no change in CMJ in INT. 2–4% decline in agility performance in INT and CON.
Zarei et al. ¹⁸² 66 males (mean age 15)	<i>II+</i>	20–25 min, ≥twice/week, 30 weeks	Illinois agility test, dribbling sprint test, 9.1 m and 36.6 m sprints, yo-yo intermittent recovery test, Bosco CMJ 15s, vertical jump height, sit-and-reach-test	Improvement in INT and CON for Bosco CMJ and vertical jump height, but significantly more in INT. Illinois agility test and 36.6 m sprint improved in INT and dribbling test in INT and CON.
Zarei et al. ¹⁸³ 31 males (mean age 12)	<i>II+ Kids</i>	15–20 min, every training session, 10 weeks	Isokinetic strength in hip abductors and adductors, knee extensors and flexors, and ankle muscles	Large positive effects in INT for all measures, small or medium sized positive effects in CON for hip abductors and ankle invertors.

Abbreviations: CON, control group; CMJ, countermovement jump; INT, intervention group; PEP, Prevent injuries and Enhance Performance, RCT, randomised controlled trial; ROM, range of motion; SEBT, Star Excursion Balance Test

Effect mechanisms of injury prevention exercise programmes

The effect mechanisms may explain why a certain effect is seen. When discussing effect mechanisms from IPEPs, the focus is on how these may affect injury rates. To evaluate the effect mechanisms of IPEPs, functional tests, such as strength and hop tests, are not sufficient²⁴. The movement quality should also be evaluated in order to assess neuromuscular function²⁴. There are many options for evaluating neuromuscular function, some more suitable for clinical settings, such as functional tests, and some more for laboratory settings, such as three-dimensional (3D) motion analysis and electromyography¹⁷⁸.

Different IPEPs have been evaluated using 3D motion analysis regarding their effects on different jump tests in different sports and populations¹⁶⁷. The results of these studies suggest that the proposed risk factors for injury, such as knee valgus angles and knee flexion angles, may be improved by the interventions¹⁶⁷. However, even where risk factors have been modified, a corresponding injury risk reduction cannot be taken for granted¹⁶⁷. Most studies are small and use different jump tests, different multi-component programmes and different populations¹⁶⁷, making comparisons difficult. Due to the challenges posed by 3D tests, the use of two-dimensional (2D) tests may be a solution to also enable testing in the field¹³⁰. Even though 2D tests cannot measure movements in the transverse plane, the correlation between 3D and 2D measures ranges from poor to excellent when measuring knee valgus from the frontal plane during drop vertical jumps¹³⁰. The highest correlation between 2D and 3D motion analysis was shown when measuring knee separation distance, and this test also showed high reliability¹³⁰. The focus in the studies included in this thesis is on pragmatic studies outside the lab, testing whole teams using simple 2D tests.

Muscle activation patterns may be altered by IPEPs and may change into a movement pattern more protective against ACL injuries^{184, 186}. In a study of female football and handball players, increased pre-activity of the medial hamstring muscle was seen after a period of IPEP training^{184, 186}. We do not know, however, how long these adaptations will be sustained in the absence of training or as the athletes get older and more mature¹⁴. One study showed that changed movement patterns after a three-month intervention were not retained, whereas movement patterns after a twelve-month intervention were, indicating the importance of long intervention periods¹³². There are few studies of youth players, even though these are at highest risk of injury^{14, 133}. All in all, there is a dearth of studies regarding the biomechanical and neuromuscular training effects of IPEPs, with few studies evaluating the same IPEP¹³³. Before the present research project commenced, no studies had been done on the *Knee Control* IPEP regarding effect mechanisms. Hereafter, IPEP effects on injury rates will be described in the context of step 4 of the TRIPP.

Scientific evaluation of preventive efficacy

Prevention of injuries

In step 4 of the TRIPP, the efficacy of preventive interventions under the ideal conditions of a randomised controlled trial (RCT) is evaluated. Most IPEPs have been evaluated regarding their preventive efficacy in RCTs or cluster-RCTs (Table 6). Overall, positive effects on injury rates have been shown from most IPEPs in youth football, with 32–48% lower rates of overall injuries, 49–65% of match injuries^{31, 131, 148, 154, 157} and 64% of anterior cruciate ligament injuries¹⁷⁶. A few studies, however, did not show any significant differences between the intervention group and control group, probably explained by low compliance¹⁶⁰⁻¹⁶¹. The lack of preventive effect from *the 11* has also been explained by the lack of progression in the programme¹⁶⁰. A systematic review covering *the 11+* (different age groups and sexes) concluded that the programme effectively reduced the rate of injury in four out of six studies, and concluded that *the 11+* appears useful in both preventing injuries and improving performance parameters among amateur players¹². Another systematic review with meta-analysis concluded that *the 11+* reduced the risk of injury by 39%, covering both youth players of both sexes and adult male players, whereas no injury risk reduction was found for the two studies covering *the 11*¹⁶⁸. Another systematic review on *the 11* and *the 11+*, including both cluster-RCTs and prospective cohort studies with players of all ages and both sexes, found an overall injury rate reduction of 35% from *the 11+*, but no significant change from *the 11*⁵. When interpreting the results of the preventive studies, it is important to keep in mind the differences in sample sizes probably rendering low power in some circumstances, especially in the sub-group analyses, and additionally acknowledging that injury definitions varied.

Athletes in their mid-teens (14–18 years) have shown superior injury preventive effects compared to early (<14 years) and late (18–20 years) teens and young adults (>20 years)^{112, 164}. Hence, it has been suggested that training should start at an early age, prior to the time when the players are most susceptible to ACL injury¹⁶⁴ and before altered neuromuscular control is seen^{112, 127}. Cost-effectiveness studies have shown that the *11+ Kids* reduced the risk of injury by 50% and reduced the costs by 51% compared to the control group¹⁴⁹. Another programme in youth football reduced the rate of lower extremity injuries by 38%, whereas the healthcare costs were reduced by 41% in the players in the intervention group¹⁰⁰.

Table 6. Effects of injury prevention programmes on injury rates in youth football

Reference	Participants	Intervention	Dosage	Effects
Emery et al. ³¹ Canada	744 males and females, (13–18 years)	'Neuromuscular warm-up'	20-week indoor season, before every training session and matches, 15 min/session + 15 min home-programme	38% reduction in overall injury rate, 43% reduction in acute injury rate. No effect on lower-extremity injuries, knee and ankle sprains.
Gilchrist et al. ⁴⁷ USA	1435 collegiate females, division I (mean age 19.9)	PEP	One season (=12 weeks), three times/week, <30 min/session	No difference in overall or non-contact ACL injury rates between INT and CON in per-protocol analysis.
LaBella et al. ⁸⁴ USA	855 high school football and basketball (mean age 16.2)	'Neuromuscular warm-up'	One season, every training session (20 min), abbreviated programme before matches	65% reduction in gradual-onset injury rate, 56% reduction in acute onset injury rate, 66% reduction in non-contact ankle sprains. No effect on knee sprains or ACL sprains.
Owoeye et al. ¹³¹ Nigeria	416 males (mean age 17.8 INT, 17.5 CON)	I/+	6 months, ≥ twice/week	41% reduction in overall injury rate, 65% reduction in match injury rate, 48% reduction in rate of all injuries to the lower extremities in INT. Most secondary outcomes did not reach significance.
Rössler et al. ¹⁴⁸ Switzerland, Czech Republic, Germany, Holland	3895 males and females (n=171 females) (mean age 10.8)	I/+ Kids	One season, ≥ twice/week, 15–20 min/session	48% reduction in overall injury rate, 74% reduction in severe injury rate, 55% reduction in lower extremity injury rate.
Silvers-Granelli et al. ¹⁵⁴ USA	1525 male collegiate division I and II (mean age 20.4 INT, 20.7 CON)	I/+	One season, 3 times/week, 20 min/session	46% reduction in overall injury rate. Numbers needed to treat to prevent one injury = 3. Four-fold risk reduction of ACL and three-fold of hamstring injuries in INT.
Soligard et al. ¹⁵⁷ Norway	1892 females (mean age 15.4)	I/+	One season, every training session, 20 min/session	32% lower rate of overall injury, 53% reduction of overuse injuries, 45% reduction of severe injuries. No effect on lower extremity injury, knee injuries or acute injuries.
Steffen et al. ¹⁶⁰ Norway	2020 females (mean age 15.4)	I/I	2 months pre-season + one season, every training first 15 times, then once a week	No difference in injury rates between INT and CON, probably partly due to low compliance.
Steffen et al. ¹⁶¹ Canada	385 females (13–18 years) Web-based, regular and comprehensive delivery	I/+	4 months (one season), all practice sessions and parts of it before matches, , 2–3 times/week, 20 min/session.	No difference in injury rates between intervention groups. Team compliance determined the reduction in injury rates.
Waldén et al. ¹⁷⁶ Sweden	4564 females (mean age 14.1 INT, 14.0 CON)	Knee Control	One season, twice/week, 15 min/session preceded by 5 minutes running warm-up	64% reduction of ACL injuries in INT. Per-protocol analysis: reduction in ACL injury rate of 83%, severe knee injury rate of 82% and any acute knee injury of 47%.

Abbreviations: ACL, anterior cruciate ligament, CON, control group; INT, intervention group; PEP, Prevent injuries and Enhance Performance

The importance of compliance to injury rates

Compliance and adherence are two concepts that are sometimes used interchangeably but should be separated since there are subtle differences between them¹⁰⁴. ‘Compliance’ may be used when discussing the uptake of interventions in efficacy trials in highly controlled circumstances and in comparison to a fixed exercise prescription, whereas ‘adherence’ can be used in effectiveness studies, i.e. in real-world contexts when the context is very likely to affect the uptake¹⁰⁴. Definitions used in this thesis follow this distinction. Studies on IPEPs have, so far, used different definitions of compliance and some have not provided details about how compliance has been measured¹⁷³. Due to the lack of homogeneous measuring and analysing of compliance, it is not possible to pool data or calculate the minimum training dose for a preventive effect, which would have been valuable information to transmit to the end-users¹⁷³.

Two kinds of compliance may be studied: team compliance and player compliance. Team compliance illustrates the training dosage for the whole team, e.g. the proportion of training sessions and matches when the IPEP has been used. Player compliance illustrates the individual player dosage, e.g. the proportion of training sessions and matches in which the IPEP was used and in which the player took part¹⁵⁸. No differences in injury risk regarding overall injuries or acute injuries have been shown when comparing injury rates in female youth teams with different compliance^{68, 158}. The reason for this is mostly that player attendance at training varies, which underlines the importance of studying compliance at a player level¹⁵⁸. In contrast, another study on *the 11+* found lower injury rates with greater team compliance¹⁵⁴.

Regarding player compliance, the *Knee Control* IPEP significantly reduced the rate of ACL injury, severe knee injury and any acute knee injury in the most compliant players, who attended football training and took part in preventive training most often, whereas the least compliant players had no injury risk reduction compared to the control group⁶⁸. Similar results have been shown in two studies regarding *the 11+* in female youth football players, with significantly fewer lower extremity injuries in the most compliant players^{158, 162} (Table 7).

Table 7. Association between compliance with injury prevention exercise programmes and preventive efficacy from randomised controlled trials in youth football players

Reference	Participants	Intervention	Definition of compliance	Effects
Hägglund et al. ⁶⁸ Sub-analysis of Waldén et al. ¹⁷⁶	2471 females, 12–17 years	<i>Knee Control</i>	Stratification in tertiles (high, intermediate and low) based on compliance. High player compliance: mean of 30 IPEP sessions, intermediate: mean of 22, low: mean of 12 sessions	88% lower rate of ACL injuries in the high-compliance tertile compared to the low-compliance tertile, also lower rate of severe knee injuries (90%) and any acute knee injury (72%). No injury rate reduction in the low-compliance players compared with CON.
Steffen et al. ¹⁶² Sub-analysis of Steffen et al. ¹⁶¹	226 females, 13–18 years	<i>II+</i>	Low player compliance: 0–113, medium 114–213, high 214–435 <i>II+</i> exercises during the season respectively	72% lower risk of injury in the high-compliance group vs. medium-compliance, 68% lower risk of lower extremity injury.
Soligard et al. ¹⁵⁸ Sub-analysis of Soligard et al. ¹⁵⁷	1055 females	<i>II+</i>	Stratification in tertiles (high, medium and low) based on compliance. High player compliance: mean of 49 sessions, intermediate 23 sessions, low 7 sessions.	35% lower risk of injury and 39% lower risk of acute injury in the high-compliance group compared to the intermediate group. No differences in injury risks between the intermediate and low compliance groups.
Silvers-Granelli et al. ¹⁵⁴	1525 male collegiate division I and II, mean age 20.4 INT, 20.7 CON	<i>II+</i>	Low team compliance: 1–19 sessions/season Medium: 20–39 sessions/season High: > 40 sessions/season	Significant difference in injury rate between the groups with different compliance. The greater the team compliance, the lower the injury rate

Abbreviations: ACL, anterior cruciate ligament; CON, control group; INT, intervention group; IPEP, injury prevention exercise programme

The intervention context

Implementation in the real-world context

In step 5 of the TRIPP model, studies of the intervention context are carried through to inform implementation strategies. Even though there are efficacious interventions, no injuries will be prevented in the real world unless coaches adopt and deliver them to the teams¹⁰¹. When programmes are less effective in the real-world context than in trial situations, this may be related to the programmes not being used as intended. Criticism has been expressed towards using only RCTs as evidence, since these are conducted under highly controlled conditions³⁷. That the target users in the real-world context are ready to adopt and maintain the IPEP is equally as important as its efficacy and effectiveness¹⁰². Therefore, evaluations in the real-world context are needed³⁷, which motivates steps 5 and 6 of the TRIPP model.

To succeed with implementation, young players should be targeted with IPEPs to implement behavioural change at an early age⁵⁷. It has been suggested that injury prevention should be a part of mandatory coaching courses for youth coaches^{57, 101}. With an increased understanding of the facilitators and barriers to the adoption and maintenance of IPEPs, implementation efforts can be targeted towards the most urgent areas³⁷. At the moment, there is still a need to extend our knowledge about implementation factors, in particular regarding adoption and maintenance within sports injury prevention^{37, 122}.

An ecological model can be used to describe the actors who may play an important role in sports injury prevention in children and youths (Figure 2)³⁰. The least responsibility is placed on the player and the most on the government and sports organisations³⁰. Most studies cover the player and coach perspective, whereas information about the other stakeholders is absent.

Figure 2. Modified ecological model based on Emery et al.³⁰, describing the different stakeholders responsible for sports injury prevention in children and youths, with increasing responsibility in the outer circles.

Implementation frameworks

To succeed in the prevention of injuries in the real-world context and to enhance the impact of IPEPs, implementation frameworks, such as the RE-AIM: Reach, Effectiveness, Adoption, Implementation and Maintenance framework, may be used^{37, 48, 124}. The RE-AIM framework focuses on issues related to the design, dissemination and implementation process that may facilitate or impede success in broad population-based interventions⁴⁹. Before the RE-AIM framework was put forth, most studies reported on the efficacy of interventions without giving much information about the generalisability of the study findings⁴⁹. The Reach and Effectiveness dimensions are individual based, whereas Adoption and Implementation are seen from an organisational point of view⁴⁸. Maintenance is seen from both perspectives⁴⁸. RCTs are often conducted on homogeneous populations under controlled conditions, which differs from the more heterogeneous real-world context, and hence intervention effects also differ, which warrants evaluations in the real-world context⁴⁸.

To better fit the complexity of team sports, the RE-AIM framework was further developed into the RE-AIM Sports Setting Matrix (RE-AIM SSM)³⁷. The RE-

AIM SSM is better suited to team interventions, in which multiple levels influence the implementation of IPEPs, such as players, coaches, clubs, and district and national sports associations³⁷. To optimise the implementation of IPEPs in team sports, all five dimensions of RE-AIM must be considered¹²². In sports medicine, there is a lack of studies reporting on the adoption and maintenance of IPEPs in team sports¹²². If the IPEPs are not adopted, executed in the correct way and maintained over time, their preventive effectiveness will not reach its full potential irrespective of how good a programme really is¹²². All five steps of the RE-AIM framework influence the potential for real-world effectiveness. One study showed that, although half of all coaches in high-school basketball and football teams were aware of IPEPs, only 21% used one, and only 9% used it exactly as intended¹¹⁷.

Reach of injury prevention exercise programmes

The Reach dimension describes the percentage of the population that has been reached by an intervention, along with the characteristics related to the participants⁴⁸. A programme that is highly efficacious but reaches very few will only have a small population impact⁴⁸. A Swiss study showed that, four years after a countrywide campaign in which *the 11* was added to a mandatory coaching course, 80% of all coaches within the Swiss FA knew about *the 11*⁷². Coaches for female high-school basketball and football players were more likely to be aware of IPEPs than coaches for male players, but just half of all coaches were aware of an effective IPEP¹¹⁷. In female youth football in Australia, nearly half of the studied coaches were not aware of *the 11+* and among those who were, only half could describe it in a fully appropriate way, despite it being incorporated into the coaching curriculum²⁸.

Effectiveness of injury prevention exercise programmes

The Effectiveness, or as it is sometimes called, Efficacy dimension, refers to results related to the positive and negative outcomes of an intervention⁴⁸. Ninety percent of the coaches who did not implement an IPEP still believed that an IPEP could reduce injury rates¹¹⁷. In female youth football, 79% of coaches believed *the 11+* to be somewhat or very effective in preventing injuries, and 64% believed it somewhat or very effective in improving player performance²⁸.

Adoption of injury prevention exercise programmes

The dimension of Adoption describes the proportion and representativeness of settings that adopt a programme⁴⁸. In one study, all the coaches agreed that injury prevention was important and that injuries may affect performance negatively, but despite this, few had adopted an IPEP¹¹⁷. In female youth football, 34% of all

coaches used *the 11+*, and when only counting those aware of the IPEP, 59% had adopted it²⁸. This was in line with the *11*, which had been adopted by 57% of Swiss coaches⁷². A study in amateur football showed that 22% of coaches adopted an IPEP if they learned about it on a coaching course⁴⁶. The decision to use an IPEP usually lies with the coach, fitness staff or team physiotherapists, even though the players are the intended beneficiaries¹²³. Few studies report on the reasons for adopting or not adopting IPEPs¹²³. Studies of the facilitators and barriers for the adoption of IPEPs are warranted in order to learn more about how they are perceived by the end-users¹²²⁻¹²³.

The facilitators for IPEP use that have been described in different team sports range from having easy access to programme materials, proper equipment, enough space for the training and support when adopting and using an IPEP, whereas the most widely reported barriers were not having enough time, poor player buy-in, lack of coaching resources and the IPEP being too difficult^{28, 105, 123, 150}. The study by O'Brien&Finch¹²³ also mentioned facilitators and barriers related to the head coach accepting the programme, attitude and motivation towards injury prevention, and staff-related issues in terms of cooperation, continuity and organisation. Another study also suggested that, in order to facilitate the adoption of IPEPs, information activities ought to focus on both 'what' to do and 'why' to do it, i.e. also educating coaches and players about injuries and how to prevent them, not only showing them the IPEP³.

Implementation of injury prevention exercise programmes

The dimension of Implementation describes the extent to which an IPEP is delivered as intended⁴⁸, and covers aspects of adherence and fidelity, the extent to which the intervention is implemented as intended across settings, and also adaptations to the intervention and costs⁴⁹. In a study by Steffen et al.¹⁶¹, three different modes of delivery of *the 11+* were compared: web-based delivery, coach-based with an educational workshop, and player-focused where physiotherapists also made regular visits to the team (in addition to coaching workshops). In the group that only received web-based delivery of the IPEP, team compliance was sub-optimal, compared to the other groups¹⁶¹.

Using the same exercises during all training sessions for an extended period of time may potentially reduce motivation among both players and coaches⁵⁰, which reveals a need to develop IPEPs that are perceived as fun and challenging and that may be tailored⁵⁰. In youth male professional football, it has been stressed that adequate variation and progression within IPEPs is important and that fun, challenging and competitive exercises and equipment need to be used¹²⁴. To facilitate use of the IPEP, team staff also emphasized the need for adaptability so that they could tailor the IPEP towards the actual context (elite/amateur football) and circumstances (pre-season, in-season...)¹²⁴. Within female youth football, most of the coaches (74%) who used *the 11+* had implemented only parts of the

programme, and additionally 44% used it less than the recommended dosage of twice per week²⁸. The most frequently reported reason for modifying programme content was to add variation, progression, challenge and individualisation¹²⁵. The underlying reason for this was to motivate the players, avoid boredom and tailor the exercises to fit individual players¹²⁵. Tailoring of IPEPs may also be necessary to meet the specific needs of a given setting¹²³.

Often, when IPEPs are introduced, it has been assumed that supplying coaches with written material and offering workshops is enough to ensure that they deliver the exercises in the right way, with high fidelity. It has also been assumed that all players will understand and execute the exercises correctly³⁹. Whether this really is the case has rarely been reported³⁹, even though it may be vital for the effect. In addition to studying whether teams use the actual exercises in an IPEP, the volume and intensity, the technique when they perform the exercises, i.e. the exercise fidelity, may also be relevant to observe for optimal preventive effect³⁹. A study of female youth football reported that some players did not concentrate upon the execution of the exercises¹⁵⁷. Recently, the exercise fidelity in football teams using the *Knee Control* IPEP has been studied using a checklist⁹². Overall, only 48% of the observed exercises were performed correctly, which may reduce the preventive effectiveness of the IPEP⁹². Another implication of these results is that coaches need more support for instructing the players in the IPEP and for supervising and correcting technique flaws⁹².

Maintenance of injury prevention exercise programmes

The dimension of Maintenance describes the extent to which interventions become stable at an organisational level⁴⁸, but also their long-term use at an individual level⁴⁹. Overall, few studies report on the maintenance of IPEPs more than six months after the initial trial¹²². Team and player adherence to IPEPs deteriorate over the season, especially among teams with the lowest adherence^{68, 158}. To achieve long-term success, the IPEP must be tailored to the specific sporting context to increase the chances of high adherence⁵⁰. This deteriorating adherence over the season motivates studies about facilitators and barriers to enable long-term use of IPEPs⁶⁸. Additionally, players ought to be encouraged to attend football training throughout the season to improve adherence with the IPEP⁶⁸. The reasons for player absences are, however, unknown at present. One study followed up on the use of the IPEP *HarmoKnee* one year after the end of the study and found that among the still-existing teams, 44% still used some parts of the IPEP and 19% used the entire programme⁷⁵.

The end-users

In addition to factors related to the IPEP, it is also important to understand the end-users to succeed with the implementation, and most of all how these end-users experience characteristics related to the programme per se, rather than their experience/belief about the programme's efficacy²⁶. The team staff plays a key role in the implementation of IPEPs¹²⁴. A study among youth female football coaches showed that all 56 coaches taking part in the study believed that including IPEPs in their training was important. Only 29% believed that the players' risk of injury was high¹⁵⁸. The coaches expressed a belief that their own motivation was vital when trying to motivate the players to use IPEPs¹⁵⁸. The strongest motivation for using the programme was an expectation of reducing injuries¹⁵⁸. Teams that showed low compliance with IPEPs were more likely to have coaches who experienced that the intervention was too time-consuming or that the programme was not football-specific enough¹⁵⁸. In female youth football, 44% of players believed that injuries were quite preventable or definitely preventable, whereas coaches in general only believed that the injuries were slightly preventable¹⁰⁵. Additionally, coaches and players only reported slight confidence in their ability to use *the 11+* for the entire upcoming season, despite having taken part in a workshop presenting *the 11+*¹⁰⁵.

Effectiveness of preventive measures in the implementation context

A better understanding is needed of the relationship between adherence to IPEPs and their effect on injury rates in the real-world context¹⁷¹. Only a few studies have focused on injury rates over time outside RCTs, which is covered in step six of the TRIPP model.

A Swedish study showed a decline in cruciate ligament injuries and acute knee injuries in football players between 2006 and 2015¹⁸⁷. The decrease in injury rates was larger in female players; however, no decrease was seen among the 15–17-year-old females¹⁸⁷. The change in injury rates was probably related to the implementation of the *Knee Control* IPEP during the time period of the study, since no similar decrease was seen in other common team sports during the same period¹⁸⁷ (Figure 3).

A Norwegian study showed positive effects on ACL injury rates after the introduction of an IPEP in female handball in 2001, but after the study ended the ACL injury rate gradually increased again from 2001 to 2005¹¹⁴. As a result of this increase, new efforts were made to disseminate the IPEP via free coaching seminars and the development of a digital versatile disc (DVD) covering video films of all the exercises and also media attention reporting the positive results of preventive studies in 2005¹¹⁴. From 2005 onwards, the ACL injury rate decreased

again and remained lower, as the promotion of injury prevention has continued since then¹¹⁴. Nationwide preventive initiatives and a focus on the coach as a key partner are believed to have contributed to this success¹¹⁴.

One study evaluated injuries in Switzerland before and four years after the introduction of *the 11* within amateur teams with players older than 14⁷². The coaches were asked retrospectively about injuries that had occurred during the preceding four weeks⁷². Teams that used the intervention had a 12% lower rate of match injuries and 27% lower rate of non-contact injuries during matches than in teams not using *the 11*⁷². However, the coaches only used 40% of the original exercises in the programme⁷². A follow-up of the previously mentioned study reported that in 2015 the teams that had implemented *the 11* or *the 11+* and used at least three of the programme exercises, at least once per week during the previous six months had a 38% lower incidence of injuries during training⁴⁶. However, the injury incidence at matches did not differ between teams that used an IPEP and teams that did not⁴⁶.

Figure 3. Incidence of knee and cruciate ligament injuries (per 1000 licenced player-years) over the years since *Knee Control* was introduced. (Reprinted with permission from Åman et al.¹⁸⁷)

Abbreviations: CD compact disc, CL cruciate ligament, DVD digital versatile disc, FA football association, RCT randomised controlled trial

RATIONALE OF THE THESIS

The *Knee Control* IPEP has been shown to be efficacious in preventing injuries. However, the effect mechanisms of why and how IPEPs, such as *Knee Control*, affect injury rates positively are not well understood at the moment. Without fully understanding the effect mechanisms and which elements are most vital for IPEP effects, all adaptations will be arbitrary and may hamper the preventive effect when made by amateur coaches. Few studies have focused on the effect mechanisms of IPEPs within youth football and few have focused on the coach's perspective. Coaches play an important role in the adoption and use of IPEPs, but their experiences of and motivators for doing this have not been studied in detail. Hence, we need to learn more about how to minimise injury rates by reaching as many coaches and players as possible, making them adopt the programme and implement it with good adherence and fidelity and also continue with preventive training over time. Since coaches and players come and go in youth football, the implementation of IPEPs is an ongoing process that never ends.

AIMS OF THE THESIS

Overall aim

The overall aim of the thesis was to improve our understanding of the effects of the *Knee Control* injury prevention exercise programme on sports performance and jump-landing technique, as well as exploring programme implementation and coach experiences of using the programme in youth football.

Specific aims

The specific aims were to:

- Study the effects of the *Knee Control* IPEP on football-relevant performance in female youth football (Study I)
- Evaluate the implementation of the *Knee Control* IPEP in female youth football (Study II)
- Explore factors affecting coaches' adoption and use of the *Knee Control* IPEP in female football (Study III)
- Study the effects of the *Knee Control* and the further developed *Knee Control+* IPEPs on jump-landing technique in youth football (Study IV).

METHODS

An overview of the studies is presented in Table 8. Each study is presented in a separate paper, consecutively numbered Papers I–IV. Study IV covered more aspects than those presented in Paper IV. In the thesis, aspects of performance effects and implementation issues will also be presented regarding Study IV.

Table 8. Description of the four studies in this thesis

	Paper I	Paper II	Paper III	Paper IV
Design	Cluster-randomised controlled trial	Cross-sectional study	Qualitative study	Cluster-randomised trial
Participants	41 female youth football players from 4 teams	352 coaches for female youth football teams, 9 football association representatives	20 coaches for female football teams	74 youth football players from 8 teams (4 male, 4 female)
Aims	Study effects of the <i>Knee Control</i> IPEP on football-relevant performance	Study the implementation of the <i>Knee Control</i> IPEP in female youth football	Explore factors affecting coaches' adoption and use of the <i>Knee Control</i> IPEP within female football	Study the effect on jump-landing technique of two versions of the <i>Knee Control</i> IPEP
Intervention	<i>Knee Control</i> versus control group	–	–	<i>Knee Control</i> and <i>Knee Control+</i>
Data collection	Performance testing indoors: balance, jump ability, agility and sprint performance, at baseline and after 11 weeks of using <i>Knee Control</i>	Three different questionnaires were sent to two groups of coaches for female youth football teams and to representatives of football associations.	Semi-structured interviews regarding the coaches' experiences of the adoption and use of <i>Knee Control</i>	Jump-landing technique testing indoors at baseline and after 8 weeks of using the respective intervention
Analysis	Descriptive statistics, independent and paired samples t-tests, Mann-Whitney U-test	Descriptive statistics	Conventional qualitative content analysis	Descriptive statistics, paired samples t-test and Wilcoxon signed rank test for the jump-landing technique tests.

Abbreviations: IPEP, injury prevention exercise programme

Context

The youth football season in Sweden starts in April and ends in October, with a summer break in July. Most amateur teams have scheduled training sessions two or three times per week and play one match per week on either natural or artificial turf, depending on what the club has access to. In some clubs, the training grounds are used extensively, limiting training times for each team.

Many players take part in other sports in addition to football, floorball and handball are particularly popular since their seasons start when the football season ends. In youth teams, the coach is usually the parent of one of the players and does his/her coaching as a spare-time activity. Some coaches take part in many coaching courses, whereas others only attend a few basic courses when they start their coaching career. No course is mandatory.

Methodology for Studies I and IV

Studies I and IV were cluster-randomised trials, with the teams as cluster units, and covered the performance effects of the *Knee Control* IPEPs. Study IV also covered tests of jump-landing technique. In Study I, teams were randomised into an intervention group (INT) using *Knee Control* and a control group (CON). The control group did its usual training, without using any aspects of an IPEP, and were offered education in the *Knee Control* IPEP after the study.

Study IV compared the original version of the *Knee Control* IPEP with a further developed version, the *Knee Control+* IPEP. At the time when Study IV was planned, the *Knee Control* IPEP was so widespread that finding teams that did not already use at least some aspects of the programme was difficult. Based on this, a pre-post study design comparing the two different interventions was chosen in order to motivate coaches to consent to participation in the study, instead of having a pure control group.

Participants

In both studies, coaches for youth teams (female teams in Study I, both male and female teams in Study IV) were approached and invited to take part in the study if their teams had scheduled training sessions at least twice per week and had not used an IPEP regularly, at least once a week, during the previous year. For inclusion, a player needed to be free of any injury or illness that would affect their participation in performance testing.

In Study I, female youth football players from four different football teams participated. In Study IV, eight youth football teams, four female and four male, participated. Baseline characteristics for the players in the two studies are presented in Table 9. In total, 52 players (INT 28, CON 24) took part in baseline

measurements in Study I, and, with eleven players lost to follow-up, 41 took part in both baseline and follow-up measurements (INT 23, CON 18). In Study IV, 115 players took part during baseline measurements, 66 boys and 49 girls, and at follow-up 77 players returned (74 analysed, 47 boys, 27 girls). At baseline, 37 boys and 28 girls were allocated to the *Knee Control* group and 44 boys and 49 girls to the *Knee Control+* group. At follow-up 21 boys and 8 girls returned in the *Knee Control* group, whereas the corresponding figures in the *Knee Control+* group were 26 and 19. No adverse events were reported in either study.

Table 9. Baseline characteristics Studies I and IV

	Study I		Study IV	
	INT (n=23)	CON (n=18)	Boys (n=47)	Girls (n=27)
<i>Knee Control</i> IPEP	23		21	8
<i>Knee Control+</i> IPEP			26	19
Age (years)	14.2 ± 0.7	14.2 ± 1.1	14.2 ± 0.7	14.0 ± 0.9
Stature (cm)	165.0 ± 6.5	164.2 ± 6.1	166.3 ± 9.8	163.9 ± 7.3
Body mass (kg)	53.9 ± 8.6	51.6 ± 7.4	54.0 ± 9.4	52.7 ± 8.9
Football experience (years)	7.6 ± 1.6	6.9 ± 2.2	7.5 ± 2.3	7.0 ± 2.0
Additional sports activity	12 (52%)	8 (44%)	23 (49%)	13 (48%)

Values are mean ± standard deviation or number of players (%). Abbreviations: CON, control group; INT, intervention group; IPEP, injury prevention exercise programme.

Interventions

Study I took place during the spring part of the season of 2010 in Linköping, Sweden, whereas Study IV took place during the autumn part of the season of 2017 in Linköping, Sweden. Due to this difference, the duration of the studies varied, with 11 weeks of training in Study I and 8 weeks in Study IV.

Both IPEPs were led by the coach, and for practical reasons all players in the team used the same level of exercises, meaning that the exercises were progressed on a team basis when the coach assessed that the players' technique had improved. In Study I, coaches were instructed to progress the training over time as the performance during training improved, whereas coaches in Study IV were contacted by telephone after two weeks and allowed, and indeed highly recommended, to progress after this check-up. Proper movement quality during all exercises was emphasised in the intervention groups.

Knee Control

The coaches, and when possible the players, were introduced to the *Knee Control* IPEP (SISU Idrottsböcker, 2005) (or *Knee Control+* in Study IV) during a practical session and received instructions on how to do the exercises in the correct way and how to progress the training over time. They were instructed to use the programme at all training sessions throughout the season (11 weeks in Study I, 8 weeks in Study IV). In Study I, coaches were instructed to use the six neuromuscular exercises with four progressions and partner exercises for 15 minutes after a short running warm-up (self-administered). In Study IV, the running warm-up exercises that were added to the programme in 2012 were used before the six neuromuscular exercises, and coaches were also recommended to use the running warm-up exercises before matches, all in all taking 5+15 minutes. In Study I, coaches in the INT were supplied with written programme material and CDs with films showing all exercises. In Study IV, all coaches, irrespective of group allocation, were supplied with the written *Knee Control* material and recommended to download the free mobile application (app) to see video films of all the exercises, and of the running warm-up.

Knee Control+

In line with the further development of *the 11* and the *PEP* programme into *the 11+*¹⁵⁷ and also the version adapted for younger players, *the 11+ Kids*¹⁴⁸, a need to further develop the *Knee Control* IPEP emerged as time passed and more and more teams started using the *Knee Control* IPEP in Sweden. So, for Study IV, the *Knee Control* IPEP was further developed, taking into account the lessons learnt, particularly in Studies II and III.

The *Knee Control+* IPEP was developed from the *Knee Control* IPEP in a collaboration between eight physiotherapists and one medical doctor who, together, had several years of experience of football training and coaching, information, workshops, and research regarding the *Knee Control* IPEP. In *Knee Control+*, the same six principal exercises/training aims were included as in the original programme, but with more possibilities for adapting the programme to particular teams in order to fit both younger and older players of different maturity. Similar to the *Knee Control* IPEP, running warm-up exercises for five minutes commenced the 15 minutes of neuromuscular training. In line with *the 11+*, more levels of progression and partner exercises were added to *Knee Control+* to better fit both the youngest and oldest youth players, along with more suggestions for the general running warm-up. *Knee Control+* has more options for progression, with six to ten different levels of exercises of increasing difficulty, in contrast to the four levels in *Knee Control*. At the time of the study, the *Knee Control+* material consisted of a written folder containing pictures and instructions for all exercises as a complement to the original performance of the exercises as described in the app. Coaches in the *Knee Control* group did not have access to material specific to *Knee Control+* during the study and were not informed about the differences between the programme versions.

Data collection

Players were tested at baseline and at follow-up at the same indoor venue wearing indoor shoes, short socks, tight shorts and t-shirts. They were recommended to refrain from physical exhaustion on the day of testing and the previous day. One team at a time was tested using a test battery that took between two and three hours to go through, depending on team size. The test battery included tests of balance, sprint, agility and jump performance, and in Study IV tests of jump-landing technique as well (Table 10). Before testing, all players took part in a standardised warm-up. The ambition was to test all teams at the same time of day at baseline and follow-up, which was feasible in all but one of the teams in Study IV. The testing order was the same during all tests. Between tests and trials, the players were allowed to rest as much as needed to be able to perform with maximum effort. Before all tests, the players were encouraged to practise thoroughly to avoid learning effects. Results of the performance tests were collected using timing gates (sprint and agility tests) (MuscleLab 4010, Ergotest Technology a.s., Norway), an infrared contact mat (test of vertical jump height) (MuscleLab 4010, Ergotest Technology a.s., Norway) or a cloth measure (horizontal hop length and balance). The tests of jump-landing technique and hop endurance were filmed using two GoPro Hero5 cameras, one from the frontal view and one from the lateral view. In both studies, all tests were assessed by blinded assessors, except the balance test (Study I) and the filmed tests (Study IV).

Table 10. Overview of the tests used to measure performance and jump-landing technique in Studies I and IV

Quality	Study I		Study IV	
<i>Performance</i>		No. of attempts		No. of attempts
Balance	SEBT	6 practice trials 3 test trials		
Vertical jump height	CMJ	2 practice trials 3 test trials	CMJ	2 practice trials 3 test trials
Horizontal jump length	Triple-hop for distance test	2 practice trials 3 test trials	Single-leg hop for distance test	3 practice trials 3 test trials
Agility	Illinois agility test	1 practice trial 2 test trials	Agility t-test 505-agility test	2 practice trials 2 test trials
Speed	10 and 20 m sprints	1 practice trial 2 test trials	10 and 20 m sprints	1 practice trial 2 test trials
Hop endurance			Side-hop test	Short practice trial 1 test trial per leg
<i>Jump-landing technique</i>			DVJ: 1) NASD, NKSD, knee flexion angles 2) Subjective assessment TJA	3 practice trials 3 test trials Short practice trial 1 test trial

Abbreviations: CMJ, countermovement jump; DVJ, drop vertical jump; NASD, normalised ankle separation distance; NKSD, normalised knee separation distance; SEBT, star excursion balance test; TJA, tuck jump assessment

Performance outcomes

Balance

In Study I, the star excursion balance test (SEBT) was used to test dynamic balance on one leg at a time (Figure 4). The player stood on one foot and tried to reach as far as possible with the toe of the other foot without losing balance. The reach distance was tested in the anterior, posteromedial and posterolateral direction. The hands were placed on the iliac crest during the whole test. A cloth measure was used to measure the distance. A test–retest reliability of 0.89–0.93 has been reported¹³⁵. Since the reach is affected by the leg length, the results were normalised to leg length, measured in supine position from the anterior superior iliac spine to the centre of the medial malleolus⁵³. A composite score of the results in the three directions was calculated in line with Plisky et al.¹³⁵.

Figure 4. Performance of the star excursion balance test in the anterior direction (picture), posteromedial and posterolateral

Vertical and horizontal jump performance

Jump performance was tested using two tests (Study I) or three tests (Study IV). In both studies, countermovement jumps (CMJ) were used to measure vertical jump height. The player started the test by going into a squat, immediately followed by a vertical jump. The hands were held on the hips and no overhead target was used. A test–retest reliability of 0.94 has been shown in youth male football and handball players¹¹⁵.

The triple-hop for distance test was used to measure horizontal jump length in Study I. The players started by standing on the dominant leg (recorded at baseline), jumped forward three times with alternating legs and finally landing on both legs⁷⁶. Free arm- and leg-swinging was allowed. A test–retest reliability of 0.84–0.88 has been shown in patients who have undergone ACL reconstructive surgery¹⁴¹.

In Study IV, the single-hop for distance test was used to measure horizontal jump length. The player started by standing on one leg and jumped as far as possible and landed on the same leg. Free leg-swing was allowed, and a balanced landing was sought. Hands were kept on the back during the test. A test–retest reliability of 0.80 has been reported in male and female recreational athletes¹⁰⁸.

Hop endurance was measured during the side-hop test for 30 seconds per leg in Study IV. The player stood on one leg with the hands on the back and hopped as many times as possible for 30 seconds between two tape markings 40 cm apart. The tests were filmed, and the number of approved hops were counted on a later occasion. The test had a test–retest reliability of 0.72 in healthy males and 0.87 in healthy females⁵⁵.

Agility

In Study I, the Illinois agility test was used to measure agility performance. The test was slightly modified and started with the player standing with one foot in front of the other at the starting line. At command, they sprinted 10 m, touched the ground and turned back, sprinted 10 m, weaved through obstacles back and forth and then sprinted 10 m again, touched the ground and turned back and sprinted 10 m over the finishing line (Figure 5). A test–retest reliability of 0.96 has been shown in youth male football players¹¹⁵.

Figure 5. Illustration of the modified Illinois agility test with straightforward running and weaving through obstacles.

In Study IV, the agility t-test and 505-agility test were used to test agility performance. In the agility t-test, the player ran 10 m forwards, side-shuffled 5 m to the left, touched the cone with the left hand, side-shuffled 10 m to the right and touched the cone with the right hand and then side-shuffled 5 m to the left and touched the middle cone with the left hand before sprinting 10m backwards to the starting position (Figure 6). The test started on command. A test–retest reliability of 0.98 has been shown in youth male football players¹¹⁵. In the 505-agility test, acceleration and speed during a 180-degree turn was tested²⁹. The player sprinted 15 m forwards, through timing gates positioned after 10 m, made a 180-degree turn at the 15 m line and sprinted 5 m back through the same timing gates again (Figure 7). A test–retest reliability of 0.95 has been shown in female netball players¹⁰.

Figure 6. Illustration of the agility t-test, with straight running (A-B), side-shuffling (B-C, C-B-D, D-B) and backwards running (B-A).

Figure 7. Illustration of the 505-agility test from a 10 m flying start running 5 m, turning, running 5 m back.

Sprint performance

Ten and 20 metre sprint tests were used to test sprint performance in Study I and Study IV. The test started on command with the player standing with one foot at the starting line and the other foot placed behind the line. A test–retest reliability for 10 m sprints has been calculated as 0.96 and for 20 m sprints as 0.95 in youth male football and handball players¹¹⁵.

Jump-landing technique outcomes

In Study IV, the drop vertical jump (DVJ) and tuck jump assessment (TJA) were used to evaluate jump-landing technique as a simple means of estimating neuromuscular control. Both tests were filmed from the frontal and lateral views and analysed on a later occasion.

Drop vertical jump

The drop vertical jump test was chosen as an evaluation of jump-landing technique since this test has been used extensively in studies involving similar populations. Before the test, a test leader fitted all players with markers on the greater trochanters, the centre of the patellae, the lateral malleoli and the lateral epicondyle of the right femur. The player stood on a box that was 30 cm high and 50 cm wide with the feet 35 cm apart, dropped down from the box and immediately made a vertical jump to try and reach an overhead target positioned 2.6 m above. The DVJs were analysed both objectively by assessment of knee and ankle separation distances and knee flexion angles, and subjectively^{116, 163}.

The subjective analysis of the frontal plane knee control during the DVJ was assessed according to the following criteria by Nilstad et al.¹¹⁶: knee alignment and/or presence of valgus and/or medio-lateral movement of one or both knees during the jump¹¹⁶. The test was rated as 0 (representing good control), 1 (reduced control) or 2 (poor control) (Figure 8). The assessment focused on the first drop, landing and preparation for take-off. All three jumps for each player were assessed and the film representing the worst technique was used for analysis. The inter-rater agreement was substantial to almost perfect (70–95% agreement and kappa values $\kappa = 0.52$ to 0.92) when classifying female elite football players¹¹⁶. The test has also been shown to identify individuals with high knee valgus angles¹¹⁶.

The objective 2D motion analysis was made in Dartfish (Dartfish Pro Suite 7) of the worst trial of the DVJ for each player, as assessed subjectively. The distance between the hip markings, the knee markings and ankle markings was measured from a frontal view in T1 (*initial contact*, the frame where the player's feet just touched the ground), T2 (*maximum knee flexion*) and T3 (*preparation for take-off*, representing the frame in which the player displayed the worst neuromuscular control between T2 and take-off from the ground)^{119–120}. Measurement of the normalised knee separation distance is seen as a correlate for knee valgus¹²⁷. Additionally, the knee flexion angle was measured from the sagittal view in T1 and T2 (Figure 9)¹¹. High test–retest reliability of the hip separation distances (intraclass correlation coefficients= 0.94 – 0.96) has been shown in female athletes¹¹⁹.

Figure 8. Subjective assessment of drop vertical jumps, depicting from left to right: good control, reduced control, poor control.

Figure 9. Measurement of normalised knee and ankle separation distance and knee flexion angles at T1 (initial contact) during the DVJ. The same measurements were made at T2 (maximum knee flexion). At T3 (preparation for take-off) knee and ankle separation distances were measured.

Tuck jump assessment

TJA was used to test jump-landing technique subjectively using ten different criteria¹¹¹. This test was chosen because it is very physically demanding for the player¹¹¹ and may put the neuromuscular control system under more stress than during DVJ⁵⁸. The dichotomised grading scale proposed by Herrington et al.⁵⁸ was used. The player jumped repeatedly for 10 seconds and attempted to lift the knees to hip level (parallel to the ground) during the jump and start a new jump immediately upon landing (Figure 10). Free practice was allowed before the single test trial. High inter-rater reliability (80–100% agreement and kappa value $\kappa=0.88$) and intra-rater reliability (87–100% agreement and kappa values $\kappa=0.86$ –1.00) was shown across the ten scoring criteria in both male and female athletes⁵⁸.

Figure 10. Performance of the tuck jump assessment, jumping continuously for 10 seconds, attempting to lift the knees to hip level and start a new jump immediately upon landing.

Questionnaires

In Study IV, the players responded to questionnaires at baseline and follow-up. The players received the questionnaires during testing and responded during the rest between tests, rendering a response rate of 100% at baseline and 99% at follow-up. The baseline questionnaire included questions about the players' training background, current training volume (both football and other sports) and interest and motivation in playing football at present. The follow-up questionnaire covered questions about their experiences of the *Knee Control* IPEPs and facilitators and barriers related to the *Knee Control* IPEPs. The follow-up questionnaire was based on questionnaires from a previous study¹⁰⁵ with influences from McKay et al.¹⁰³ and O'Brien and Finch¹²³, but adapted to suit the *Knee Control* IPEPs and the present context.

Statistical methods

In both Study I and Study IV, the best result was used for analysis regarding the performance tests, whereas the worst result from the analyses of the DVJs were used in Study IV.

Sample size calculations were made beforehand in both studies, based on 80% power at an alpha level of 0.05 and expecting a 10% (Study I) or 5% improvement (Study IV) and a drop-out rate of 20%. In Study I, the primary outcome measure was the CMJ, resulting in an estimated sample size of 42 players. No sample size calculation was made based on results of the jump-landing tests for Study IV. Due to low compliance and a high drop-out rate among the female players in two of the teams in Study IV, only male players were included in the analyses of performance effects. A sample size calculation based on the mean and standard deviation of male players during the agility t-test (primary outcome measure) gave an estimated sample size of 34 players.

The INT and CON in Study I were compared at baseline using an independent samples t-test or Mann Whitney U-test depending on the test variable. In Study I, absolute change scores from baseline to follow-up were calculated for both INT and CON and compared using an independent samples t-test for between-group comparisons. Within-group comparisons from baseline to follow-up were made using a paired-samples t-test.

In Study IV, the jump-landing tests were primarily presented descriptively. Additionally, statistical significance was tested within groups using a paired samples t-test for the objective analysis of DVJ and the Wilcoxon signed ranks test for the subjective assessments of DVJ and TJA. For the analysis of the performance tests, mixed-design ANOVAs were used to analyse the effect over time and for comparisons between the *Knee Control* group and the *Knee Control+* group on each performance test, adjusted for age. Effect sizes, Cohen's *d*, were calculated for significant within- and between-group results in both studies, based on the means and standard deviations. Effect sizes, *r*, were calculated for non-parametric data in Study IV based on $Z/\sqrt{N}$, where *N* equals the number of observations. For the between-group comparisons regarding performance in Study IV, effect sizes, partial eta-squared, were calculated and converted to Cohen's *d*. Effect sizes were interpreted as: small *d*=0.2, medium *d*=0.5, and large *d*=0.8 or small *r*=0.1, medium *r*=0.3 and large *r*=0.5¹⁹. The results of the questionnaires in Study IV were described descriptively.

The primary analysis conducted was according to the intention-to-treat principle. In both intervention studies, the significance level was set at $p < 0.05$. The coaches registered team and player compliance with the intervention, whether the team had used the intervention or not and whether the respective player had taken part or not. Unfortunately, in Study IV two of the coaches were unable to return player data on compliance, but only reported team compliance, making per-protocol analyses impossible.

Methodology for Studies II and III

Studies II and III covered different aspects related to the implementation of the *Knee Control* IPEP.

Study II was a cross-sectional study evaluating the implementation of *Knee Control* three years after the initial RCT, covering the preventive efficacy of the programme¹⁷⁶ and two years after nation-wide implementation of the programme started. Data collection was carried out during the winter of 2012–2013.

Study III was a qualitative study centred upon interviews with coaches for female football teams. Data collection started in late 2014 and ended before the summer of 2015. Interviews were analysed using qualitative content analysis⁸⁰.

Participants

In Study II, three groups of stakeholders were approached to complete questionnaires that were based on the RE-AIM SSM to cover different aspects of the implementation:

1. *Trial coaches* – Coaches who had participated in the earlier RCT covering eight football districts¹⁷⁶ (n=303)
2. *Current coaches* – Coaches who were actively coaching in 2012 (n=496) in the same eight study districts but who were not involved in the earlier RCT
3. Representatives of the same eight district football associations and for the national football association (n=9).

The *trial coaches* were all coaches who had taken part in the study conducted by Waldén et al.¹⁷⁶, and were included in the present study irrespective of whether they were still coaching a team or not. All *trial coaches* were educated (INT) or offered education (CON) during the previous study and were sent information about the results of the RCT when it ended. The *current coaches* were all actively coaching female youth teams in 2012. *Trial coaches* who were still active only received the questionnaire for *trial coaches*, not the one for the *current coaches*. With 173 *trial coaches* and 179 *current coaches* responding, the response rate was 57% and 36% respectively. All FA representatives responded.

In Study III, coaches from the same eight districts as in Study II were approached by e-mail. The coaches were strategically selected based on whether they belonged to clubs that had taken part in the earlier RCT or not, and also to represent both rural and urban areas. All had used the *Knee Control* IPEP but for different lengths of time to give a wide variety of experiences regarding the use of the *Knee Control* IPEP according to maximum variation sampling. Coaches were contacted consecutively until 20 had consented to participate. All in all, 50

coaches were contacted, six declined to participate and 24 did not respond. The participants were free to choose the location for the interviews and, hence, 19 interviews were conducted over the phone, whereas one was conducted face to face. None of the participants had any previous connection to the interviewer and had not taken part in earlier studies on the *Knee Control* IPEP. The mean age of the coaches was 44 years (range 23–52 years) and 16 were the parent of (at least) one of the players in the team. Most coached youth teams with players aged 10–17 years. Nine of the coaches had used the *Knee Control* IPEP for less than 1.5 years, 11 for 2–8 years, one had just started and four had stopped using it after 0.5–5 years.

Data collection

Web-based questionnaires based on the RE-AIM SSM covering the reach, effectiveness, adoption, implementation and maintenance of the *Knee Control* IPEP were sent to the coaches in Study II. The original definitions of each dimension were modified slightly to better suit the context. The questionnaires to the FA representatives focused on factors related to the maintenance of the *Knee Control* IPEP. The items were generated by the researchers, guided by the RE-AIM SSM. Most items were polytomous and had fixed tick-boxes, but there were also a couple of open-ended questions. Three items in the coaches' questionnaires were scored on a numerical rating scale (NRS) from 0 to 10, where 0 represented the least and 10 the most favourable option. The questionnaires were accessed via a link sent to a personal e-mail address to the coach or representative in question. By contacting *trial coaches* and district and national FAs the active planned, spread of the *Knee Control* IPEP was evaluated, whereas the *current coaches* gave a picture of the passive spread of the *Knee Control* IPEP.

The interviews in Study III were supported by a semi-structured interview guide informed by the Health belief model (HBM)⁷¹. The benefit of using a health behaviour theory or model is that it ensures that multiple perspectives are covered⁴³. Within sports medicine injury prevention studies, the most frequently used health behaviour theories and models are the Theory of Planned Behaviour and the HBM⁴³. The interview guide had five open-ended questions (Table 11) and additional probes that were used when necessary. Probes regarding reasons for the adoption of *Knee Control* were influenced by the HBM constructs of perceived susceptibility, severity, benefits and barriers, and additionally cues to action and self-efficacy. In addition to the HBM, an ecological perspective was embraced when probing for more thorough answer; for example, by asking whether coaches were influenced by any other factors than those that they had already mentioned during the interview. Prior to the 20 main interviews, pilot interviews were carried out with two other coaches to test the interview guide and analysis procedure. The interviews were audio-recorded and transcribed

verbatim. None of the coaches had any relation to the interviewer beforehand. The interviews lasted 39 minutes on average (range 23–56 minutes).

Table 11. Interview guide and probes used in Study III

Main questions (in bold) and probes
What do you think about the use of <i>Knee Control</i>? How did you first encounter the programme? Do you see any benefits of using the programme? Are there any barriers for using the programme? Do you feel any support in using the programme? What effects do you think the programme has? What about injury risks in football? In your team compared to other teams? How come?
Do you have any experience of injuries or among e.g. players in your team? Have you experienced any knee injuries yourself? How did you experience these injuries? Why do you think they occurred?
What do you think about your role as a coach? Why did you choose to become a coach? What do you think about your coach education? What do you think about your ability to instruct your players about the exercises?
Do you use the programme in your team? What were your reasons for starting to use the programme? Were there any particular reasons for continuing to use the programme? How do you use the programme? Is this how you think the programme was intended to be used? Are there any particular reasons behind your decision not to use the programme? What would make you start using the programme (again)?
If you could wish for anything regarding <i>Knee Control</i> and preventive actions – what would that be?

Data analysis

In Study II, most items in the three questionnaires were of nominal or ordinal level scales and presented descriptively. The NRS was treated as an ordinal level scale and continuous variables as interval level.

In Study III, the interviews were analysed using qualitative content analysis⁸⁰. As little was known about the subject beforehand, conventional content analysis was chosen⁶⁴. The analysis was inductive without predefined categories and with a focus on responding to the study aim. The pilot interviews were analysed together by three members of the research group and, as the results did not differ substantially, the primary author conducted the succeeding analyses on her own and these were discussed when all the interviews had been analysed. Initially, the transcripts were read repeatedly and meaning units – extracted parts of the text that responded to the study aim – were marked, condensed and coded.

Preliminary codes were created using words and phrases from the coaches, but these were later reworded to better cover the content of the condensed meaning units. Codes with related content were grouped together into categories and sub-categories that were intended to be internally homogeneous and externally heterogeneous. An iterative process was applied, moving back and forth between

analysis and transcripts and forming new categories until a pattern emerged and thereafter using these categories and adding new ones when necessary. As a final step, a negative case analysis was carried out to make sure that all the codes had been correctly categorised.

Ethical considerations

All four studies were approved by the regional ethical review board in Linköping, Sweden. Participating players and their legal guardians (Studies I and IV) and coaches (Studies II–IV) received written information about the studies and signed written informed consent forms prior to the study start. Even though the coach was first asked whether his or her team would take part in the studies, all players were free to choose whether they wanted to take part in testing and data collection or not in Studies I and IV. Players and their legal guardians in Study IV also signed forms if they consented to their films made during testing being shown in research or education activities. Coaches taking part in Study III received a guarantee that no information that could connect their statements with themselves would be published. Consent was obtained from the national FA representatives in Study II to publish their responses, even though their answers could not be anonymised.

The risk of harm, such as delayed onset muscle soreness, was considered to be far outweighed by the benefits of introducing the *Knee Control* IPEP and achieving a high spread by supporting facilitators and avoiding barriers. Activities to test performance in Studies I and IV are common in senior football, but rarely conducted in youth football so the study was an opportunity for participating teams to gain access to similar tests as professional football players and also learn about their individual results. The studies are especially valuable from a public health perspective since the focus in this thesis was on learning more about how implementation may be supported.

RESULTS

Effects on performance and jump-landing technique

In this section, the results from Studies I and IV, evaluating IPEP effects on performance and jump-landing technique, will be presented.

Performance measurements

No significant improvement in performance was seen over time in the intervention group in Study I for any performance measure (Table 12). Significant between-group changes were seen from baseline to follow-up favouring the CON regarding sub-scores of the SEBT and the Illinois agility test and representing small to medium effect sizes ($d=0.3-0.6$).

In study IV two players were excluded from the analyses of performance effects due to injuries preventing full participation in testing. No performance improvements were seen over time in Study IV when analysing the sample as a whole; instead, small deteriorations were seen in the agility t-test, CMJ and 10 m sprint (Table 13). When analysing the intervention groups separately, small improvements were seen over time in the 505-agility test and side-hop test on the right leg in the *Knee Control* group. The only between-group difference was found in the 505-agility test, with a significant interaction effect between the 505-agility test and group allocation, $F(1,44)=10.42$, where players in the *Knee Control* group improved their performance over time, whereas players in the *Knee Control+* group performed worse over time, $\Delta_{KC \text{ vs } KC+}=-.012$ (95% CI $-.19$ to $-.04$), $d=0.98$.

Table 12. Results of baseline and follow-up tests, within-group (ΔW) differences and between-group differences in change between baseline and follow-up (ΔB) in Study I on female youth players

	INT (n=23)		CON (n=18)		ΔW (95% CI)	ΔW (95% CI)	ΔB (95% CI)
	Baseline	Follow-up	Baseline	Follow-up			
SEBT (cm)							
right posterolateral	115.3 $\pm$ 9.8	116.2 $\pm$ 9.1	111.4 $\pm$ 8.5	116.7 $\pm$ 10.2	0.9 (-2.5, 4.3)	5.3 (1.9, 8.7)	-4.3 (-9.1, 0.5)
right posteromedial	110.6 $\pm$ 9.3	111.0 $\pm$ 8.4	106.9 $\pm$ 7.4	110.5 $\pm$ 9.2	0.4 (-2.8, 3.5)	3.6 (0.4, 6.8)	-3.2 (-7.6, 1.3)
right anterior	101.2 $\pm$ 7.2	99.6 $\pm$ 7.6	98.3 $\pm$ 8.1	96.9 $\pm$ 6.6	-1.6 (-3.5, 0.2)	-1.4 (-4.4, 1.6)	-0.2 (-3.5, 3.1)
left posterolateral	118.7 $\pm$ 10.4	115.9 $\pm$ 9.0	113.8 $\pm$ 8.4	116.1 $\pm$ 9.4	-2.8 (-6.2, 0.6)	2.2 (-2.2, 6.6)	-5.1 (-10.4, 0.2)
left posteromedial	109.6 $\pm$ 9.2	110.5 $\pm$ 7.7	106.1 $\pm$ 6.6	112.0 $\pm$ 9.6	0.9 (-2.2, 4.0)	5.9 (2.5, 9.2)	-5.1 (-9.6, -0.6)
left anterior	101.0 $\pm$ 7.1	98.7 $\pm$ 5.5	98.6 $\pm$ 8.5	99.3 $\pm$ 7.9	-2.3 (-4.9, 0.4)	0.7 (-2.9, 4.3)	-3.1 (-7.3, 1.2)
composite score right	109.0 $\pm$ 8.0	108.9 $\pm$ 7.4	105.5 $\pm$ 7.3	108.0 $\pm$ 7.8	-0.1 (-2.4, 2.2)	2.5 (0.4, 4.6)	-2.6 (-5.7, 0.6)
composite score left	109.8 $\pm$ 7.9	108.4 $\pm$ 6.6	106.2 $\pm$ 6.9	109.1 $\pm$ 8.2	-1.4 (-3.5, 0.7)	2.9 (0.0, 5.9)	-4.3 (-7.7, -1.0)
CMJ (cm)	25.5 $\pm$ 3.7	25.0 $\pm$ 4.0	24.5 $\pm$ 3.1	24.6 $\pm$ 3.2	-0.43 (-1.1, 0.2)	0.1 (-0.9, 1.2)	-0.55 (-1.7, 0.6)
Triple-hop for distance (cm)	523 $\pm$ 55.1	506.0 $\pm$ 52.5	527.0 $\pm$ 53.3	525.0 $\pm$ 43.0	-17.1 (-26.1, -8.2)	-1.5 (-18.7, 15.7)	-15.6 (-34.6, 3.3)
Illinois agility test (s)*	17.43 $\pm$ 0.89	17.50 $\pm$ 0.83	17.39 $\pm$ 0.71	17.20 $\pm$ 0.83	0.06 (-0.08, 0.21)	-0.20 (-0.34, -0.05)	0.26 (0.06, 0.46)
Sprint test (s)*							
10 m	2.02 $\pm$ 0.11	2.02 $\pm$ 0.12	2.00 $\pm$ 0.08	2.01 $\pm$ 0.10	-0.01 (-0.03, 0.02)	0.004 (-0.02, 0.03)	-0.01 (-0.05, 0.03)
20 m	3.58 $\pm$ 0.19	3.57 $\pm$ 0.23	3.52 $\pm$ 0.15	3.52 $\pm$ 0.17	0.003 (-0.03, 0.03)	0.004 (-0.03, 0.04)	0.00 (-0.05, 0.05)

Values are mean $\pm$ standard deviation. * Data analysed for 17 players in the control group and 22 players in the intervention group. Bold text indicates statistical significance $p < 0.05$. Abbreviations: CI, confidence interval; CMJ, countermovement jump; SEBT, star excursion balance test.

Table 13. Results at baseline and follow-up, and comparisons of change between groups in Study IV on male youth players

		Mean (95% CI)		Between-group difference in change (95% CI); p-value; Cohen's d	
Agility t-test (s)	Baseline (1)	Whole sample (n=47)	Knee Control (n=21)	Knee Control+ (n=26)	
	Follow-up (2)	11.89 (11.68 to 12.11)	12.24 (11.92 to 12.56)	11.61 (11.33 to 11.89)	
	Change (2)-(1)	12.03 (11.82 to 12.24)	12.30 (11.97 to 12.63)	11.81 (11.52 to 12.1)	-0.14 (-0.40 to 0.12); p=0.293; d=0.32
Single-leg hop for distance, right leg (cm)	Baseline (1)	0.14 (0.02 to 0.25)	0.06 (-0.12 to 0.25)	0.20 (0.04 to 0.37)	
	Follow-up (2)	143.15 (138.92 to 147.38)	140.4 (133.6 to 147.2)	145.3 (139.2 to 151.3)	
	Change (2)-(1)	143.40 (138.35 to 148.46)	139.6 (131.4 to 147.7)	146.4 (139.2 to 153.6)	-2.03 (-8.64 to 4.57); p=0.538; d=0.19
Single-leg hop for distance, left leg (cm)	Baseline (1)	0.26 (-2.62 to 3.13)	-0.87 (-5.53 to 3.79)	1.16 (-2.97 to 5.3)	
	Follow-up (2)	143.73 (138.49 to 148.98)	139.7 (131.3 to 148.1)	146.9 (139.4 to 154.4)	
	Change (2)-(1)	144.43 (138.91 to 149.94)	140.0 (131.2 to 148.9)	147.9 (140 to 155.7)	-0.62 (-9.59 to 8.34); p=0.889; d<0.02
505-agility test (s)	Baseline (1)	0.69 (-3.19 to 4.57)	0.35 (-5.98 to 6.67)	0.97 (-4.64 to 6.58)	
	Follow-up (2)	2.60 (2.55 to 2.64)	2.63 (2.56 to 2.7)	2.57 (2.5 to 2.63)	
	Change (2)-(1)	2.61 (2.57 to 2.65)	2.58 (2.51 to 2.65)	2.63 (2.57 to 2.69)	-0.12 (-0.19 to -0.04); p=0.002; d=0.98
Side-hop right (m)	Baseline (1)	0.01 (-0.02 to 0.05)	-0.05 (-0.1 to -3.18)	0.07 (0.02 to 0.11)	
	Follow-up (2)	37.75 (34.33 to 41.16)	37.63 (32.07 to 43.19)	37.83 (32.9 to 42.76)	
	Change (2)-(1)	39.28 (35.31 to 43.24)	42.71 (36.38 to 49.03)	36.50 (30.89 to 42.11)	6.41 (-0.63 to 13.46); p=0.073; d=0.55
Side-hop left (m)*	Baseline (1)	1.53 (-1.63 to 4.70)	5.08 (0.11 to 10.05)	-1.33 (-5.74 to 3.07)	
	Follow-up (2)	35.61 (31.65 to 39.57)	34.21 (27.8 to 40.62)	36.77 (30.97 to 42.58)	
	Change (2)-(1)	37.83 (33.69 to 41.96)	37.00 (30.28 to 43.72)	38.51 (32.43 to 44.59)	1.05 (-5.79 to 7.89); p=0.759; d=0.09
10 m sprint (s)	Baseline (1)	2.22 (-0.71 to 5.15)	2.79 (-1.97 to 7.54)	1.74 (-2.56 to 6.04)	
	Follow-up (2)	1.88 (1.85 to 1.91)	1.88 (1.83 to 1.92)	1.87 (1.83 to 1.92)	
	Change (2)-(1)	1.90 (1.86 to 1.93)	1.91 (1.85 to 1.96)	1.89 (1.84 to 1.94)	0.014 (-0.029 to 0.057); p=0.521; d=0.19
20 m sprint (s)	Baseline (1)	0.02 (0.01 to 0.04)	0.03 (0.00 to 0.06)	0.01 (-0.01 to 0.04)	
	Follow-up (2)	3.37 (3.31 to 3.42)	3.38 (3.28 to 3.47)	3.36 (3.28 to 3.44)	
	Change (2)-(1)	3.39 (3.33 to 3.45)	3.39 (3.29 to 3.49)	3.39 (3.31 to 3.48)	-0.016 (-0.078 to 0.047); p=0.616; d=0.16
CMJ (m)	Baseline (1)	0.03 (-0.00 to 0.05)	0.02 (-0.03 to 0.06)	0.03 (-0.01 to 0.07)	
	Follow-up (2)	0.25 (0.24 to 0.26)	0.24 (0.22 to 0.26)	0.25 (0.24 to 0.27)	
	Change (2)-(1)	0.24 (0.23 to 0.25)	0.23 (0.21 to 0.25)	0.25 (0.23 to 0.26)	-0.002 (-0.02 to 0.015); p=0.801; d=0.06

A ge-adjusted results for the two intervention groups at baseline and follow-up, and their change between time points, as well as between-group differences in change. Bold text indicates statistical significance p<0.05. *Data analysed for 25 players in the *Knee Control+* group. Abbreviations: CMJ, countermovement jump; CI, confidence interval.

Compliance with the interventions

In Study I, the INT teams used the *Knee Control* IPEP on 18 out of 18, and 20 out of 21 training sessions respectively during the 11-week intervention, corresponding to 1.6–1.8 times per week. The mean player attendance at training, $60\% \pm 14\%$, led to low player intervention compliance, with the average player completing 11 ± 3 sessions with the *Knee Control* IPEP during the intervention period.

In Study IV, the teams performed a mean of 14 IPEP sessions (range 11–21), e.g. 1.4–2.6 times per week, for 10–30 minutes per session. There were eight weeks between baseline and follow-up, but three of the teams did not have scheduled training sessions during one or two of those weeks. One of the teams in the *Knee Control+* group cancelled training sessions due to heavy rain and waterlogged football grounds for two weeks. All teams progressed the training after two to four weeks of training.

Effects on jump-landing technique

For the analysis of jump-landing technique in Study IV, both male and female players were included. Of the 77 players who returned for follow-up measurements, three players were excluded due to injuries preventing full participation in the measurements. Additionally, markers were not visible during the analysis of knee separation distances in one or several instances for eight players. For one boy, no frontal view video was obtained during the TJA due to a technical error at baseline, and this test was excluded.

When comparing intervention groups, no changes were seen in the performance of DVJ over time, except for an increase in knee flexion angle at initial contact ($+3.4^\circ$, 95% CI 0.8 to 6.0, $p=0.013$, $d=0.41$) in the *Knee Control+* group. An increased number of jumps was seen during the TJA at follow-up in both groups but no other change in TJA was seen. Since minimal differences between the *Knee Control* IPEPs were seen, further analyses were made with both intervention groups combined.

In the baseline subjective assessment of the DVJ, 30% of the boys and 22% of the girls displayed good knee control (Table 14). There was no change in the performance of the DVJ in either boys or girls over time in the subjective assessment. In the 2D motion analysis of normalised knee separation distance, boys had knee-to-hip-ratios of 77–96% and girls 67–86% at T1, T2 and T3. The normalised knee separation distance at T1 decreased in the boys at follow-up (mean change -4% , $p=0.042$, 95% CI -8.4 to -0.2 , $d=-0.30$). In girls, a significantly higher knee flexion angle at initial contact (T1) was seen at follow-up (mean change $+4.7^\circ$, $p<0.001$, 95% CI 2.4 to 7.0, $d=0.74$).

Table 14. Subjective assessment and results of the objective 2D motion analysis of the drop vertical jump test at baseline and follow-up in Study IV

	Boys (n=47)		Girls (n=27)	
	Baseline	Follow-up	Baseline	Follow-up
<i>DVJ subjective assessment</i>				
Good control n (%)	14 (30%)	10 (21%)	6 (22%)	6 (22%)
Reduced control n (%)	22 (47%)	24 (51%)	16 (59%)	20 (74%)
Poor control n (%)	11 (23%)	13 (28%)	5 (19%)	1 (4%)
<i>2D analysis of DVJ*</i>				
NKSD T1 % (SD)	96 ± 15	92 ± 14	86 ± 9	86 ± 12
NKSD T2 % (SD)	84 ± 27	80 ± 26	76 ± 16	76 ± 20
NKSD T3 % (SD)	77 ± 25	76 ± 25	67 ± 21	71 ± 14
Knee flexion angle T1 degrees (SD)	26.9 ± 7.1	29.0 ± 8.2	22.7 ± 6.0	27.4 ± 5.0
Knee flexion angle T2 degrees (SD)	93.1 ± 14.8	90.6 ± 11.6	87.0 ± 10.3	89.5 ± 10.5

Values are n (percent), ratio ± standard deviation or degrees ± standard deviation. The table displays NKSD at T1: initial contact, T2: maximum knee flexion and T3: preparation for take-off. Bold text indicates significantly different results ($p < 0.05$) compared to baseline. *n= 44–46 boys and 25–27 girls due to markers being occluded during some time points of the video assessment. Abbreviations: DVJ, drop vertical jump; NKSD, normalised knee separation distance; SD, standard deviation.

The most common flaws during the TJA are presented in Table 15. No change was seen in the TJA total score in boys, whereas an improvement was seen in girls over time with the median score changing from 4 at baseline to 3 at follow-up ($p = 0.045$, $r = -0.39$). Both sexes achieved significantly more jumps at follow-up. When analysing the results criterion by criterion, no differences were seen between baseline and follow-up in boys for any criteria, whereas there was a significant improvement in girls for two criteria.

Table 15. Number of players presenting with each flaw during the tuck jump assessment in Study IV

	Boys (n=46)*		Girls (n=27)	
	Baseline	Follow-up	Baseline	Follow-up
Tuck jump criteria				
1. Lower extremity valgus at landing	20 (43%)	26 (55%)	19 (70%)	20 (74%)
2. Thighs do not reach parallel (peak of jump)	28 (60%)	31 (66%)	20 (74%)	19 (70%)
3. Thighs not equal side-to-side (during flight)	24 (51%)	26 (55%)	9 (33%)	11 (41%)
4. Foot placement not shoulder width apart	29 (62%)	29 (62%)	13 (48%)	11 (41%)
5. Foot placement not parallel (front to back)	12 (26%)	10 (21%)	5 (19%)	8 (30%)
6. Foot contact timing not equal	3 (6%)	3 (6%)	0 (0%)	1 (4%)
7. Excessive landing contact noise	9 (19%)	12 (26%)	16 (59%)	10 (37%)
8. Pause between jumps	3 (6%)	3 (6%)	7 (26%)	2 (7%)
9. Technique decline prior to 10 seconds	4 (9%)	5 (11%)	8 (30%)	1 (4%)
10. Does not land in same footprint	29 (62%)	30 (64%)	19 (70%)	17 (63%)
Tuck jump assessment total score median (range)	3 (3–4)	4 (3–5)	4 (4–5)	3 (3–5)
Number of jumps mean ± SD	15.5 ± 1.7	16.4 ± 2.0	15.1 ± 1.7	16.0 ± 1.1

Values are n (percent), mean ± standard deviation or median (range 25th to 75th percentiles). Bold text indicates significantly different results ($p < 0.05$) compared to baseline. * One player missing from the assessment due to technical error when filming. Abbreviations: SD, standard deviation

Experiences of the *Knee Control* and *Knee Control+* programmes

At follow-up, the players in Study IV reported that they had followed the coach's instructions to a high degree and performed the exercises in the correct way and with maximum effort. Most were positive about using the programme the following season (Table 16). The two interventions received almost similar responses.

Table 16. Player experiences of the *Knee Control* and *Knee Control+* programmes at follow-up, as reported by the players in Study IV

Statements	All (n=76)	<i>Knee Control</i> (n=29)	<i>Knee Control+</i> (n=47)
<i>During the season as we have used Knee Control / Knee Control+...</i>	Median (range)	Median (range)	Median (range)
My risk of sustaining an injury has... (1 – increased, 7 – decreased)	5 (5–6)	5 (4.5–6)	5 (5–6)
My physical skills such as balance, agility and strength has improved (1 – false, 7 – true)	5 (4–5)	5 (4–5)	5 (5–5)
I was able to follow the coach instructions about completing the programme (1 – a little, 7 – a lot)	6 (6–7)	6 (6–7)	6 (6–7)
I completed the exercises in the proper way (1 – unsure, 7 – sure)	6 (6–7)	6 (5.5–7)	6 (6–7)
I could perform the exercises in the programme with 100% effort (1 – false, 7 – true)	6 (6–6)	6 (6–7)	6 (6–6)
If my team uses the programme during the next football season this is... (1 – negative, 7 – positive)	6 (5–6)	6 (5–6)	6 (5–6)

Likert scale 1–7, where 1 represented the least favourable state, and 7 the most favourable. Values are median (range 25th to 75th percentiles).

The players also reported on programme facilitators and barriers. Almost every player (96%) appreciated that the exercises may reduce their risk of injury and that performance improved over time. Few stated that they did not like the programme at all (Table 17).

Table 17. Facilitators and barriers regarding the *Knee Control* and *Knee Control+* programmes as reported by the players in Study IV

Facilitators	All (n=76)	<i>Knee Control</i> (n=29)	<i>Knee Control+</i> (n=47)
<i>What are some of the things you DID like about doing the <i>Knee Control</i> / <i>Knee Control+</i> programme?</i>	n (%)	n (%)	n (%)
The exercises may reduce my risk of injury	73 (96)	28 (97)	45 (96)
Doing exercises that are different to usual football practice	33 (43)	11 (38)	22 (47)
Doing a set warm-up with the same exercises each time	22 (29)	8 (28)	14 (30)
Feeling like I was getting better at doing the exercises	63 (83)	23 (79)	40 (85)
The exercises could be progressed over time	21 (28)	11 (38)	10 (21)
I became a better player by using <i>Knee Control</i> / <i>Knee Control+</i>	24 (32)	13 (45)	11 (23)
Doing some exercises together in the team	34 (45)	12 (41)	22 (47)
That we could compete in some exercises	21 (28)	7 (24)	14 (30)
That the ball was used in some exercises	25 (33)	7 (24)	18 (38)
Nothing, I did not like the programme	2 (3)	0 (0)	2 (4)
Barriers			
<i>What are some of the things you DID NOT like about doing the <i>Knee Control</i> / <i>Knee Control+</i> programme?</i>	n (%)	n (%)	n (%)
I didn't understand the reason for the exercises	2 (3)	0 (0)	2 (4)
The exercises were too hard	2 (3)	0 (0)	2 (4)
The exercises were too easy	9 (12)	3 (10)	6 (13)
The exercises were boring	25 (33)	8 (28)	17 (36)
The programme was too long	17 (22)	8 (28)	9 (19)
We had limited time to practise other football drills	41 (54)	14 (48)	27 (57)
The exercises were not specific enough for football	14 (18)	4 (14)	10 (21)
The exercises were painful	11 (14)	2 (7)	9 (19)
Nothing, I really enjoyed the programme	21 (28)	8 (28)	13 (28)

Implementation of *Knee Control*

Study II was analysed and described based on the five dimensions of the RE-AIM SSM. Of the responding *current coaches*, 74% were male with a mean age of 44 years, and 73% of the *trial coaches* were male with a mean age of 46 years.

In terms of Reach, 91% of the *current coaches* and 99% of the *trial coaches* from the previous control group reported that they were familiar with the programme (Table 18). The programme was well perceived with high satisfaction with the *Knee Control* IPEP and high confidence in the programme's ability to reduce acute knee injuries and enhance performance.

The adoption of the *Knee Control* IPEP ranged from 72% (*trial coaches* in INT) to 58% (*trial coaches* in CON). Seventy-four percent of the *current coaches* reported that they had adopted the programme. The utilisation fidelity with the intervention protocol was low among those who used the *Knee Control* IPEP, many had modified its contents, and many used it only sporadically.

Among the *trial coaches* who continued to coach female adolescent teams after 2009, the use of the *Knee Control* IPEP remained fairly stable over time. An intention to continue using the programme, or to start using it again, at the time of follow-up was expressed by 60% of the still-active *trial coaches* in the intervention group and 73% in the control group.

At an organisational level, the Swedish FA had formal written policies regarding the implementation of the *Knee Control* IPEP, and informal guidelines were present in two of the eight district FAs. Most of the *current coaches* (87%) reported that their club had not established any routines for the use of the programme. Coach and physiotherapist education was held annually during 2010–2012 by the Swedish FA, the district FAs and some clubs to varying extents.

Table 18. Implementation of *Knee Control* among coaches according to the RE-AIM SSM framework

RE-AIM SSM dimension	Trial coaches (n=173)	Current coaches (n=179)
Reach		
Knowledge of the programme, n (%)	CON 80/81 (99)	162/179 (91)
Effectiveness		
Injury prevention NRS, median (range)*	8 (7–9)	8 (7–10)
Performance improvement NRS, median (range)*	8 (6–9)	8 (7–9)
Satisfaction NRS, median (range)*	8 (7–9)	8 (7–10)
Coaches receiving complaints from players, n (%)		
More than a few	5/126 (4)	
A few	49/126 (39)	
No complaints	72/126 (57)	
Coaches receiving complaints from parents, n (%)		
More than a few	0/124	
A few	6/124 (5)	
No complaints	118/124 (95)	
Adoption		
Coaches using the programme, n (%)	INT 49/68 (72); CON 40/69 (58)	132/179 (74)
Implementation		
Fidelity with the programme, n (%)		
Use every week		63/179 (35)
Use sporadically		69/179 (39)
Do not use the programme		47/179 (26)
Use the entire programme †	10/43 (23)	34/130 (26)
Use programme with modifications †	33/43 (77)	96/130 (74)
Maintenance		
Routines for programme use, n (%)		
Have routines		16/178 (9)
Have plans		8/178 (5)
No routines or do not know		154/178 (87)
Education via the club, n (%)		
Education offered		45/175 (26)
Plans to offer education		10/175 (6)
No education		77/175 (44)
Do not know		43/175 (25)
Use of the programme in 2012, n (%)‡		
Use every week	INT 6/16 (38); CON 6/22 (27)	
Use sporadically	INT 7/16 (44); CON 9/22 (41)	
Do not use the programme	INT 3/16 (19); CON 7/22 (32)	
Intention to continue using the programme, n (%)	INT 18/30 (60); CON 22/30 (73)	

* Median NRS on a 0–10 scale where 0 represented the least favourable option and 10 the most favourable and (range 25th to 75th percentiles) reported for *trial coaches* n=124–126, and *current coaches* n=104–106. † Reported for the coaches who used the programme. ‡ Reported for the still active *trial coaches*.

Abbreviations: CON, control group in the randomised controlled trial; INT, intervention group in the randomised controlled trial; NRS, numerical rating scale (0–10); RE-AIM SSM, Reach, Effectiveness, Adoption, Implementation and Maintenance Sports Setting Matrix

Adoption and use of *Knee Control*

In Study III, one overall theme based on the latent, underlying content, three categories and eight sub-categories emerged from the analysis. The theme *Interacting influences on coach adoption and use of Knee Control* illustrates a close connection between the three categories (Table 19). The individual coach and his or her motivation was crucial for *Knee Control* adoption and use, but it was also influenced by external facilitators and barriers, and by the characteristics of *Knee Control*. Hereafter, each category will be described in detail.

Table 19. Overview of the theme, categories and sub-categories that emerged in Study III

Theme	Categories	Sub-categories
Interacting influences on coach adoption and use of <i>Knee Control</i>	Coach motivation for adoption and use of <i>Knee Control</i>	Views on injuries in football
		Injury prevention attitude
		Beliefs about the effects of <i>Knee Control</i>
	External facilitators and barriers for adoption and use of <i>Knee Control</i>	Social support when adopting and using <i>Knee Control</i>
		Resources for use of <i>Knee Control</i>
		Player-related factors influencing the use of <i>Knee Control</i>
	Programme characteristics affecting adoption and use of <i>Knee Control</i>	<i>Knee Control</i> fit <i>Knee Control</i> feasibility

Coach motivation for adoption and use of *Knee Control*

The coaches saw football as an injury-prone sport, especially for girls. Most coaches had experience of acute and/or overuse injuries and believed that multiple factors contributed to injury occurrence. Some coaches, however, thought that the reasons why injuries occur were unclear, and some thought they knew too little.

Most coaches were driven by their own convictions about the importance of injury prevention and their own experiences of injuries and their consequences. Some found injury prevention a necessity for further football playing and suggested that it should be mandatory in girls' teams. However, some parental coaches lacked conviction that injury prevention was important and

predominantly saw football as a way to offer girls a meaningful spare-time activity. Some coaches stated that it was a matter of prioritisation and, without buy-in from the coach, no regular use of *Knee Control* would take place.

The coaches believed that *Knee Control* had positive effects on performance and injury rates if used regularly and with continuity. Some coaches, however, thought that the effects of *Knee Control* were too small to make preventive training a priority.

External facilitators and barriers for adoption and use of *Knee Control*

The coaches believed that peer exchange between coaches was an efficient way of spreading information about *Knee Control* and this was the way some coaches first came into contact with it. A few coaches had learnt about *Knee Control* via their club and district FA or during general coaching education. In general, few coaches felt supported by the club or district FAs. Because new coaches come and go all the time, some coaches stressed that information about *Knee Control* has to be spread continuously.

The preventive training was often led by one of the coaches, whereas the other team coaches prepared the forthcoming drills. The training was usually only carried out when the designated coach was present or had left clear instructions for the other coaches. Many coaches, predominantly parental coaches, asked for more support and feedback when using the exercises; for example, from an expert visiting the team or from practical education.

Resources in terms of financial resources, time, access to indoor and outdoor venues, access to *Knee Control* materials and coach availability also influenced the use of *Knee Control*. Many coaches used the app when choosing exercises and as a basis for the execution of the exercises. One challenge was that most teams were dependent on parental coaches and non-profit commitment, which limited the time and possibility for using *Knee Control*.

Coaches also believed that their use of *Knee Control* was influenced by the players. When coaching the youngest players, some exercises were too difficult, but the players were more curious and positive towards the training compared with later on. Over time, some coaches planned to let the players take over responsibility for *Knee Control* training, either by doing the exercises together with the team without being led by the coach or individually at home. However, others emphasised that the training needs to take place within the team and be led by a coach. Many coaches believed that there was a need to improve player movement quality and motivation when using *Knee Control*. Coaches who believed in the effects of *Knee Control* did their best to work around these external barriers.

Programme characteristics influencing adoption and use of *Knee Control*

The coaches found the *Knee Control* IPEP easy and safe to use. The fact that it was perceived to contain simple exercises that the coaches recognised and understood facilitated its use. Some believed that it was necessary to tailor exercises over time to fit player maturity. In addition to preventing injuries, coaches believed that the training needs to be fun since the players are, after all, there to play football. The coaches appreciated the partner exercises because they believed these increased player motivation. To make *Knee Control* fit the team even better and gain more positive experiences from the players, they wished for more examples of progression and modifications. Many had already modified *Knee Control*, for example by adding other exercises, variants of the existing exercises (also with equipment) and competitive elements, selecting a few exercises per session or doing exercises in between other drills. Weather and climate conditions were also a reason for modifying *Knee Control*.

The way in which coaches used *Knee Control* varied over time and season, and among coaches, but the training dose was usually lower than that recommended. Some did almost the same exercises every time, whereas others varied them. Some used all six exercises every session, others used a few exercises per session. To attain good continuity, several coaches recommended establishing a routine to make preventive training as natural as warming up has now become. Most coaches believed that correct execution of the exercises was important for maximising the effect; and hence, most coaches instructed, gave feedback and corrected the players during *Knee Control* training.

DISCUSSION

The main findings were that *Knee Control* and *Knee Control+* had limited effects on jump-landing technique in girls, whereas performance as measured in Studies I and IV did not improve in boys and girls after using the programme for 8–11 weeks during football training. The programme was widespread and appreciated by the coaches, but nevertheless had been modified regarding training dosage and/or content, potentially limiting its preventive effectiveness. The coaches saw themselves as vital for *Knee Control* adoption and use, but were also affected by external facilitators and barriers and the programme itself. As policies and guidelines for *Knee Control* adoption and use were missing in many district FAs and clubs, many coaches needed more support when adopting and using the programme. Additionally, they wanted a more user-friendly programme that could easily be tailored to the specific context.

Results of the intervention studies

No performance effects in Studies I and IV

No positive effects on performance were found in the tests used in Studies I or IV, but there were improvements in the control group or improvement in one intervention group and deterioration in the other. The studies imply that the main effect mechanism behind the injury reduction from IPEPs is not related to performance enhancement, at least not as measured in Studies I and IV. Even though the effect sizes in some instances were medium or large, such as for the 505-agility test, where the *Knee Control* group improved, whereas the *Knee Control+* group deteriorated, the absolute difference was only 0.07 seconds. This probably has no clinical relevance. In Study I, most of the significant results with medium or large effect sizes favouring the control group were related to the SEBT, which was measured using a cloth measure. A test–retest reliability of 0.89–0.93 had been reported previously¹³⁵, but intra-class correlations showed lower values ranging from 0.63–0.77 between the three measurements made in each direction at baseline for each player⁸⁸. Hence, probably low measurement accuracy in the actual population contributed to the large effect sizes. The results were in line with a study on the *PEP* programme that did not show any effects on performance measures in girls after 12 weeks of training¹⁷⁴. In contrast, studies on the *11+* and *11+ Kids* showed positive results on performance measures, even though some also showed improvements in the control groups^{45, 137, 147, 162, 182}. The studies had a duration of eight (Study IV) to 11 (Study I) weeks, which was in line with all but one¹⁸² previous study, which had a 30-week intervention period. In both studies, player compliance was sub-optimal, and the individual training dose became low. The player compliance of 1.6–1.8 sessions per week in

Study I and 1.4–2.6 sessions per week in Study IV was, however, rather similar to the training dose of 1–2 sessions per week which had positive effects on performance in the other studies that reported on compliance^{147, 162}.

It is also important to consider that both studies were made in-season, with follow-ups at the end of the season. Other factors, such as total training dosage and match-play, apart from the *Knee Control* training may have affected test results. After a short period of match congestion, reduced strength has been shown¹⁸⁰⁻¹⁸¹. Half of the players also engaged in other sports activities besides football, adding to the overall amount of training.

Another reason for the absence of positive results in the performance measures may be that the population was included during a period of growth and maturation, and thus the players may have had reduced ability to perform optimally. Three different factors may have contributed: 1) difficulties in focusing on the task and performing with maximum effort during training and testing, as identified by Soligard et al.¹⁵⁸, 2) temporary regression of motor control during a growth spurt¹⁴⁰ and 3) the training stimuli needed to elicit positive training effects and the potential for improvement may vary during adolescence since development during puberty is asynchronous, with different abilities developing at different ages¹⁷⁰. Both studies included players with a mean age of 14. In contrast, studies showing positive effects on performance included younger players (mean age of 10 or 12) who may not yet have reached the growth spurt^{45, 137, 147}, or older players^{20-21, 142}. Hence, expecting improvements may be unrealistic in this age-group. Unaffected results on performance tests may be positive, since these may imply that the risk of injury has not increased. This is valuable when studying youths at a time when injury rates are known to increase, particularly in girls^{152, 175}. Finally, it also needs to be acknowledged that the specificity between training and testing was low, with the programme exercises being performed in a slow and controlled manner, whereas testing included explosive muscle actions such as jumping and sprinting.

Limited positive effects on jump-landing technique

Limited positive effects on the jump-landing technique tests were found in the girls, whereas no effect was seen in the boys. The limited results are in line with other studies^{7, 52, 78}. The improvements seen in the girls represented medium to large effect sizes, in knee flexion angle, TJA total score, two of the separate TJA criteria and number of jumps during TJA. The only effect seen in the boys was an increase in number of jumps during TJA. The small improvements seen in the TJA among the girls is positive since females have a higher risk of acute knee injury than males¹⁷⁵. The potential for improvement may also have been higher in girls since they performed worse at baseline. *Knee Control* and *Knee Control+* seemed to have similar effects when comparing the results from the intervention groups. Considering risk factors for injury, knee valgus seemed unaffected by the interventions as assessed in the TJA and the DVJs. While some argue that knee

valgus is a natural movement, which needs to be controlled rather than avoided²², decreasing lower extremity valgus and increasing knee flexion angles in jumping/landing and cutting are often seen as important targets for IPEPs^{79, 86}. Hence, it is positive that the knee flexion angles improved in the girls in Study IV. Additionally, an overall better jump-landing technique at follow-up was seen among the girls according to the TJA total score. How these results affect the overall risk of injury is, however, unknown. Considering that the risk of acute knee injury is higher in females than in males generally, the study shows promising results by indicating that movement patterns may be changed by the interventions.

The implementation of *Knee Control* in youth football

Low fidelity with the programme protocol

The *Knee Control* programme was launched in 2005, and in 2008 the Swedish FA initiated a research programme to study its efficacy. The results of that RCT¹⁷⁶ formed the starting point for the national implementation of *Knee Control*. The implementation area has received more attention lately but is still lagging behind studies covering injury epidemiology and injury risk factors. Hence, Studies II and III gave valuable insights into the implementation context.

The results of Study II showed that perceptions of the *Knee Control* IPEP were positive, with high levels of belief in the programme's effectiveness. Positive experiences were valuable since the coaches' attitudes are crucial when introducing interventions^{37, 158}. The adoption rate and experiences of the programme were also positive, but nevertheless the coaches modified programme content and/or dosage. In addition to the low player compliance seen in the intervention studies, the utilisation fidelity according to the programme protocol was low, with only 35% using the *Knee Control* IPEP every week and only 26% using the entire programme. An implication of this is that the implementation of the *Knee Control* IPEP will be an ongoing project. That utilisation fidelity is low with IPEPs is supported by a few other publications^{28, 125}, implying that this may be a general problem of IPEPs.

The maintenance of 60% (*trial coaches* from former control group) to 73% (*trial coaches* from former intervention group) was rather similar to the 63% that was reported in Swedish female adolescent football one year after the implementation of *HarmoKnee*⁷⁵ and the 57% in Swiss amateur football one to three years after the implementation of *the 11*⁷². Many coaches reported that their clubs did not have any routines for programme use and few clubs offered education in the programme. Additionally, the district FAs involved in Study II did not have any formal policies for the implementation and use of the programme, even though

this may facilitate successful injury prevention³⁷. The conclusion from Study II was that the support around coaches could improve and that the modifications seen may risk compromising the preventive effect. This is supported by the study by Åman et al.¹⁸⁷, showing a reduction in ACL injuries from using *Knee Control* in the real world, but not of the same magnitude as shown in the RCT when the preventive efficacy was first established¹⁷⁶.

Coaches are vital for programme adoption and use but they need support

As a direct result of Study II, Study III was planned to further our understanding of the coaches' perspective. This took a unique approach, using qualitative methodology and incorporating health behaviour theories and models. In Study III, it was shown that the coach is vital for *Knee Control* adoption and use, which validates studies from the coaches' perspective. Even if the coach was affected by external factors and the IPEP itself, it was he/she who chose whether to use the programme or not. Coach self-efficacy in using IPEPs was important for its use. In a study on the *11+*, low self-efficacy was found among coaches, and it was recommended that further implementation initiatives should consider how to strengthen coach self-efficacy in using IPEPs¹⁰⁵. The way in which the three categories mutually affect each other also corroborates the need for more external support, as shown in Study II. The incorporation of *Knee Control* into the coaching course curriculum is positive from this perspective, since it shows that this is a prioritised issue in the national FA.

Facilitators for programme use, such as access to programme materials, having proper equipment and enough space for the training, and barriers, such as lack of time, a tough competition schedule, poor player buy-in and lack of coaching resources, have been reported^{105, 123, 150}. The same facilitators and barriers were mentioned by the coaches in Study III, but the importance of social support and the prioritisation of IPEP use, in addition to a user-friendly IPEP, were also mentioned. Knowledge about these facilitators and barriers may guide the development of IPEPs, as well as the information material and workshops, as it did for *Knee Control+*. Known barriers may also be mentioned during the workshops, together with suggestions for how these may be overcome⁴³.

Need for an update of *Knee Control*

During the years that have passed during Studies I–IV, there has been a technical development that affected the *Knee Control* IPEP: the change from use of written programme material and CDs to an app and webpage, facilitating access to the programme. Since the addition of the running warm up to the neuromuscular exercises, *Knee Control* and *11+* are quite similar and the differences are probably of minor importance when discussing the potential for effect. However, both programmes have been subjected to modifications^{28, 89-90, 125}. These modifications are probably inevitable if the same IPEP is to be used by players

between the ages of 10–12 up to senior level, as is the case with *Knee Control*. *Knee Control+* was developed to fit both the youngest and the oldest players, with its many exercises to choose from. Coaches in Study III reported that some players lacked motivation and did not appreciate the preventive training. Having many exercises to choose from can hopefully facilitate both coach and player buy-in and further smooth the way for coaching preventive work within teams.

Study III showed that the coach was affected by both external factors and the programme itself, whereas he/she in turn affected these external factors and the programme. When developing strategies to improve *Knee Control* adoption and use, the focus can be on either three, or all of them. For feasibility and pragmatic reasons, further efforts were directed to the latter category, the programme itself, in future research projects. One implication of the qualitative Study III and the questionnaires in Study II was that *Knee Control* needed modifications, since many coaches had already done this on their own, with the risk of compromising the preventive effect. The development of *Knee Control+* was informed by the results of Studies II and III in order to hopefully better satisfy the coaches.

The *Knee Control+* IPEP was developed to meet the coaches' expressed needs and also to match up with what they believed the players wished for. A project group was put together with eight physiotherapists and one medical doctor. Some had experience as football coaches, football players, team medical staff, researchers and/or programme developers, and all had used the *Knee Control* IPEP. In an initial project group meeting at the beginning of 2017, preliminary exercises were chosen and tested with different teams. When testing the exercises in a team setting, all coaches and players were asked to give feedback about the exercises. In May 2017, a meeting was held where it was decided which exercises to use in a preliminary programme, which was tested during summer in different teams (youth, elite, male, female). In August 2017, before Study IV started, the written programme material was decided upon, with photos and descriptions of each exercise ready to be launched. Between meetings, the written material was circulated within the project group. The primary author managed all feedback and updated the material accordingly.

The programme material and its distribution may still be developed in order to overcome barriers and facilitate the use of *Knee Control+*. The trend today is to have end-users take part in programme development and planning for implementation^{3, 27}. It is particularly valuable that the origins of *Knee Control+* stem from lessons learnt from interviews with coaches and that it was tested on teams that were able to give their feedback on the programme in pilot studies before Study IV. Study IV may be seen as a feasibility study enabling minor updates of the programme to work around the barriers noted, before further studies are initiated and *Knee Control+* is officially launched. It is also important to acknowledge that adaptations may be necessary in order to succeed with the implementation of IPEPs, depending on the target group and setting¹²².

Modifying programme content may also improve the chances of coaches adopting and using the programme and, hence, facilitate long-term use.

Study IV was only the first study to include *Knee Control+* and further studies are obviously needed to study its effects on injury rates. To date, the programme seems to be at least as feasible as the original *Knee Control*. To succeed with the implementation, the *Knee Control+* material must be as user-friendly as possible. By different means, efforts have been made to try and improve team compliance, by supporting coaches with an updated programme that better fits both the youngest and the oldest players and includes more suggestions for progression. However, there is still the issue of player compliance, which remains to be studied in future studies. Study IV implied that the players were rather satisfied with both *Knee Control* IPEPs and that they had faith in the programme's effects, suggesting that the problem is not the programme itself.

The potential for real-world effectiveness

So, all in all, the *Knee Control* IPEPs were subjected to low utilisation fidelity, like similar IPEPs. This may affect the real-world impact of the intervention. A mathematical example using numbers from earlier *Knee Control* studies: if the *Knee Control* IPEP reduces ACL injuries by 64%, 91% of coaches are aware of the programme, and 74% of those have adopted it, then about 43% of all ACL injuries will be prevented. Taking into account that only 35% implement it properly and that 82% maintain it, then only 12% of all ACL injuries will be prevented. If exercise fidelity proves to be important for the effect, this figure is reduced even further. We know that exercise fidelity in a similar context using the *Knee Control* IPEP was around 50%⁹². One reason behind these difficulties may be that a coaching behaviour change is needed. Even though coaches are usually the main programme deliverers, behaviour change is needed in other stakeholders as well, such as players, clubs and organisational representatives, in order to succeed with real-world implementation of IPEPs³. Behaviour change may be hard to achieve and, hence, it is often easier to implement other kinds of preventive measures, such as regulations or use of protective equipment, that demand less of a behaviour change from the coaches or players⁷⁷. In conclusion, work must continue to improve the adoption, fidelity and maintenance of IPEPs to enable even more players to benefit from preventive training.

Methodological considerations

This thesis improves our understanding of the effects of the *Knee Control* IPEPs, apart from the effects on injury rates, covering TRIPP step 3, and improves understanding of the implementation context (TRIPP step 5) and the measures that must be taken to try to achieve good effectiveness as well as efficacy. Some strengths and limitations in the study designs, measurements and analyses, however, need to be acknowledged.

The strengths of these particular studies were: the design including a control group (Study I), sample size calculations that preceded inclusion (Studies I and IV), high team compliance (Studies I and IV), well-established performance and jump-landing technique tests that facilitate comparisons between studies (Studies I and IV), tests with good measurement properties (Studies I and IV), blinded assessments (Studies I and IV), use of a tool for implementation (Study II), use of health behaviour theories and models (Study III) and efforts to increase study credibility (Study III).

Limitations were primarily: low player compliance (Studies I and IV), lack of exercise fidelity data (Studies I and IV), lack of blinding of assessors of the subjective tests (Studies I and IV), lack of blinding of players and coaches (not feasible) (Studies I and IV), floor and ceiling effects of subjective measurements (Study IV), low response rate (Study II) and small sample size (Study III).

Hereafter, the strengths and weaknesses will be described in detail.

Design of the intervention studies

At the same time as the studies on the *Knee Control* IPEP were under way, the programme in itself has gone through changes. The running warm-up has been added, video films of all the exercises have been distributed via the app or webpage, and *Knee Control* information has been included in the coaching course curriculum. Additionally, the programme has been given a lot of media attention. This has also affected the study methodology. When the first studies were conducted, few people had heard of a preventive programme and many were curious about *Knee Control*. At that time, it was easier to recruit teams for the studies for two reasons: 1) few teams were excluded based on previous experience of IPEPs and 2) few teams declined participation for other reasons. By the time Study IV was carried out, many teams had already used an IPEP, but not regularly, and having a pure control group was not as feasible.

One strength of Study I and Study IV was that they were preceded by sample-size calculations and that study size was not arbitrarily chosen. In both studies, the sample sizes were in line with the calculations beforehand, even though the studies were not powered for sub-group analyses. In the performance and jump-landing technique tests, which were unaffected by the interventions, the

confidence intervals did not indicate a trend towards improvement and there does not seem to be any risk of a type II error. Another strength with the intervention studies was that, in Study I, female youth players were included, whereas the participants in Study IV were male and, irrespective of sex, the results were the same. It was also positive that tests of different capacities (balance, agility, sprint, jump ability) were included in the same study to give an overall view of football-specific performance.

The short duration of the intervention studies may potentially be seen as a limitation. The training dosage per week was similar to the study on injury rates¹⁷⁶, but with shorter duration of the intervention. Eight or 11 weeks ought to be enough to elicit training effects on performance, even if these effects may be larger with longer duration. This is, however, also dependent on the actual training dosage per week. Regarding jump-landing technique, a single exercise bout with adequate feedback may be enough to affect it¹⁵, even though this may not have long-lasting effects. There is no optimal solution for intervention studies evaluating performance effects, since following whole teams for an entire season, across the summer break, may be subject to bias as well if not all activities that the players engage in are registered. A better idea would be to follow teams from pre-season to end of season, but this is not ideal either since not all youth players participate in team training during pre-season.

What the control group did as warm-up was not controlled for in Study I and it is possible that the warm-ups were not very different, even though the CON did not use a specific IPEP intended to prevent injuries. To the author's knowledge, no study has registered what the warm-up in youth football teams naturally looks like. Most important for a warm-up is that it really is a proper warm-up, not that it enhances performance. One has to consider whether performance improvements are really sought. If the training stimulus was high enough to elicit performance improvements, the following sports performance after the warm-up would probably suffer⁷⁰, and that is not the intention with IPEPs.

Compliance and fidelity considerations

Information about compliance is necessary when considering the efficacy of interventions¹⁷³. The high team compliance with coaches using *Knee Control* or *Knee Control+* on the majority of training sessions was a strength in both Study I and Study IV. Even though the ambition was to collect player compliance data for all players, this proved difficult, since two coaches were not able to transfer this information in Study IV. This is a limitation. For the other teams in Studies I and IV, rather low player compliance was seen. The reason for this was mostly that player attendance at training varied. This seems to be a universal problem since it has been reported for both female youth and male youth professional football players in other contexts as well^{124, 158}.

Another limitation was that exercise fidelity was not assessed. An exercise fidelity checklist was recently developed as a tool for registering whether the *Knee Control* exercises were carried out using the correct technique or not⁹². This information would have been valuable when interpreting the results of Studies I and IV. It was interesting to note, however, that most players in Study IV believed that they had done the exercises with the correct technique. Even with the checklist, the instructions that the coach gives to the players and how the coach decides to structure the training will not be covered. However, if adherence and exercise fidelity are registered in future studies, it will be easier to interpret the results of intervention studies.

Testing performance and jump-landing technique

One strength of Studies I and IV was that testing was done in an indoor venue to avoid being affected by weather conditions. Both intervention studies were pragmatic and included whole teams with rather simple tests that may be used on the field by the coaches. This was both good and bad: less measurement accuracy than 3D testing in the lab but better ecological validity and results that may be more meaningful to the players and coaches. It was also positive that the tests used in Studies I and IV were tests that had previously been used extensively in football to enable comparisons of results across studies. Another strength was that all tests, except the balance test and the filmed tests, were assessed by blinded assessors who were unaware of the randomisation, which reduces the risk of bias. A limitation was that, for practical reasons, the other tests, which also had a higher degree of subjectivity, were not measured by blinded assessors. It was also not possible to blind coaches and players regarding group allocation.

Both of the jump-landing technique tests that were subjectively assessed suffered from large floor and ceiling effects, potentially limiting the room for improvement. Compared to what has been recommended for individual targeting of faulty jump-landing technique (six flaws or more, according to Myer et al.¹¹⁰, the players in Study IV already performed relatively well at baseline and showed a median of three (boys) and four (girls) flaws at baseline, limiting the room for improvement. With the results at hand, using the new three-graded scale would probably have been better at capturing change⁴⁰. One way to “cheat” during TJA would be to jump at a slower pace to avoid fatigue¹⁵⁶. At the moment, this is not taken into account in the total score. Study IV showed an increased jump rate, which gives further support to the improvements seen among the girls. When using the TJA, it is also important to consider that not all criteria carry the same weight regarding ACL injury risk. Some criteria may be more important than others, but are still treated the same way in the TJA total score⁴¹. For this reason, the change in each criterion, as well as change in the TJA total score, were analysed.

The subjective analysis of DVJs was also affected by ceiling and floor effects. This test was originally designed as a screening test^{116, 163} and whether it is responsive to change has not been studied. When following the change in each player, it must be acknowledged that some improved, whereas others deteriorated. Hence, this test may not be ideal as an outcome measure in the present sample of developing youths, who may display large intra-individual variation in test results.

It would also have been interesting in the performance and jump-landing technique studies to follow programme effects on injury rates at the same time. This was not feasible because the sample sizes when studying injury rate reductions of IPEPs are considerably larger.

Reflections upon implementation study methodology

One way to succeed with the implementation of IPEPs is to incorporate different health behaviour theories and models¹⁰². Using a framework, such as the RE-AIM, may also be a contributing factor⁴⁸. The strengths in the methodology of the implementation studies were that Study II was based on the RE-AIM SSM and Study III incorporated the Health belief model and an ecological perspective. Additionally, the qualitative methodology gave exclusive insight into the coaches' experiences of the *Knee Control* IPEP and ideas for improvement. Altogether, these factors are strengths in the implementation studies. It is also a strength that all five dimensions of the RE-AIM SSM were included. Including four different target groups also made Study II a thorough evaluation of the implementation of *Knee Control*. The strengths of Study III were the semi-structured interview guide and open-ended questions, which made it possible to delve deeply into the experiences of the coaches. With the inductive approach, interviews could be analysed without any preconceptions. The study credibility was strengthened by having three researchers involved.

One limitation of Study II was that the questionnaires were not validated. They were pilot tested, which could have been more thoroughly done by including more coaches and using a different methodology, such as cognitive interviews. The low response rate must also be considered when discussing the results of Study II. A limitation in all four studies, but most prominently in Study III with its small sample size, was that the characteristics of the individual coaches may affect the results. In qualitative studies, generalisability of the study findings can never be guaranteed. Readers of qualitative studies must always determine whether the results are transferable to their own context, but efforts were made to facilitate high study trustworthiness in Study III.

Clinical implications

To be able to prevent as many injuries as possible, the IPEP needs to be used by as many teams as possible. Considering the limited or absent results on jump-landing technique and performance tests compliance is probably important. Based on the high team compliance seen in Studies I and IV, and the fairly high adoption and maintenance rates seen in Study II, the coaches are keen to adopt the IPEP.

The low player compliance indicates that training attendance is low in youth football. A prerequisite to prevent injuries is that the players take part in IPEP training, which is difficult to accomplish if they do not attend football training. Hence, it is vital that the players, who play football matches, also prepare thoroughly by taking part in football training and in the IPEPs used during the warm-up before training and matches.

One way of supporting coaches was to develop the *Knee Control+* IPEP based on suggestions for improvements needed in the original *Knee Control* IPEP to facilitate use and maintenance. Coaches who are satisfied with the original *Knee Control* programme can continue with that programme, until proven differently effective. Coaches who are looking for more options to tailor the programme to their team can choose *Knee Control+* instead. Irrespective of programme version, the focus should be on proper technique during training.

From a physiotherapeutic point of view, the successful implementation of IPEPs may lead to fewer injuries that need clinical examinations and rehabilitation. This is especially valuable considering that severe injuries can lead to long rehabilitation duration and risk of residual symptoms. Preventing injuries is also valuable from a public health perspective since sports injuries may be both burdensome and costly.

Transferability of study findings

When considering generalisability and transferability, it is important to consider who participated and who did not. Uninterested coaches may obviously have declined to participate in all four studies. When Study I was planned, the *Knee Control* IPEP was not widespread, i.e. many coaches may have been curious about the programme and taken the opportunity to get help with its adoption because, by accepting participation, they would be supplied with the programme material and receive education about the programme. The situation in Study IV was not the same. By that time, the programme was widespread and easily accessible via the app. The most motivated coaches may already have started using it, and thus could not take part in the study. It may have been the least informed or least motivated coaches who were left to include. According to the Diffusion of Innovations theory developed by Rogers¹⁴⁵, not everybody is as

prone to adopt innovations such as *Knee Control*, some are innovators or early adopters and are quick to adopt new innovations, whereas others are more sceptical and adopt innovations late. Applied to these intervention studies, the coaches in Study I may have represented the first categories, whereas those in Study IV the latter. Whether this may have affected the potential for effect cannot be estimated at present.

The case in Studies II and III is of course different, but still it is possible that the coaches taking part in Study II had greater knowledge about the *Knee Control* IPEP since they chose to take part. The rather low response rate (36% *current coaches*, 57% *trial coaches*) in Study II must be borne in mind when considering the results. In Study III, experience of the programme was a prerequisite for participation and, hence, the experiences of coaches choosing not to use the programme was not covered, even though some coaches who had stopped using the programme took part. This means that it is possible that the picture described by Studies II and III may be more positive than the overall general opinion.

Future research

Several issues remain to be studied, but the most important based on this thesis are:

- The performance and jump-landing technique studies were performed using simple tests at baseline and follow-up. To better understand the effect mechanisms, it would also be valuable to evaluate muscle activation patterns with electromyography immediately after having taken part in a session of *Knee Control*, as well as comparing muscle activation patterns after a season of *Knee Control* training. Using 3D tests in the lab for outcome measurements would also add valuable insights into the effect mechanisms of IPEPs.
- Since implementation is an ongoing process, it would also be valuable to study it, using the RE-AIM SSM, over the years since the *Knee Control* IPEP was added to the coaching education curriculum to see whether use of *Knee Control* has become manifest in the clubs. It would also be interesting to compare the results with those of Study II as well as the results of the national study conducted by Åman et al.¹⁸⁷.
- The question of whether compliance and fidelity with *Knee Control+* are better than for *Knee Control*. This is important because one reason for the development of *Knee Control+* was to avoid modifications made by coaches that may compromise the preventive effect.

Some other issues also remain to be studied:

- The preventive effect of *Knee Control+* needs to be established in an RCT if it is to be an addition to, or replacement for, the original *Knee Control* IPEP. Preferably, both acute and overuse injury rates should be followed throughout a season with the interventions within youth football, since the effects on overuse injuries have not yet been established for *Knee Control* or *Knee Control+* in football.
- The player perspective has not been covered in detail. Since the players are the end beneficiaries, this is important if we are to truly succeed with long-term maintenance. It would be valuable to learn more about their thoughts and feelings regarding the *Knee Control* IPEPs, but also their reasons for participating in football, to better understand the low player attendance at football training. Few studies have covered the player perspective so far, with the few exceptions focusing on professional football or senior football¹²³.
- The effectiveness of the *Knee Control* IPEPs in the real-world context. A prerequisite for this would be a national/local injury registration system covering all the injuries that occur in youth football.

CONCLUSIONS

Limited positive effects were found on jump-landing technique tests in football playing girls, whereas no effect was seen in boys. This is positive considering the increased risk of severe knee injuries in females and considering that these effects were seen despite the short study duration and low training dosage. However, no clinically meaningful effects of the *Knee Control* or *Knee Control+* IPEPs in the performance tests used in the studies were found in boys or girls. It is possible that this was related to the poor player compliance and short study duration. *Knee Control* was well perceived by youth football coaches and widely adopted. Nevertheless, many coaches reported modifying the programme to better fit their team. When given more exercise suggestions, such as those available within the further developed *Knee Control+*, arbitrary modifications made by coaches will hopefully decrease. This remains to be confirmed in later studies. Coaches are key in the use of IPEPs, but need more support. With more support from clubs and football associations, better buy-in from players and resources for programme use, in addition to a programme that is user-friendly, the adoption and use of IPEPs will hopefully be supported.

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FACULTY OF MEDICINE AND HEALTH SCIENCES

Linköping University Medical Dissertation No. 1694, 2019

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