CHAPTER 7

General discussion
Sport injuries present a significant health problem at an individual and public health level. As such, sport injuries counteract the many inherent health benefits related to regular physical activity and sport participation. Prevention of sport injuries is an important prerequisite to maintain and increase a healthy physically active lifestyle and to maximise the pursued (health) benefits from such a lifestyle. Actual prevention of sport injuries in real-world sport settings requires large-scale adoption and correct use of evidence-based preventive measures by the target population. This, in general, requires a change in the preventive behaviour of the target population within the sport injury context. As such, a wide evidence base on effective preventive measures and knowledge on effective strategies to translate and implement available evidence into broad practice are necessary to improve population health. The main aim of this thesis was, therefore, to gain insight in the effectiveness of such strategies using two different approaches: (i) summarising and evaluating available evidence on intervention strategies used in sport injury prevention studies, and (ii) describing effect and process evaluations of three nationwide interventions aimed at increasing the broad uptake of evidence-based preventive measures in real-world sport settings. These studies were included as examples of how different intervention strategies can contribute to effective implementation, that is, rule and regulation changes, health communication, and the use of a mobile application. In this chapter the main findings of this thesis are presented and discussed, together with the strengths and limitations of the methods used. Finally, implications and recommendations for practice and future sport injury prevention research are presented.

**Conceptual models**

It is acknowledged that, in order to accomplish sport injury preventive effects at a population level, both a systematic approach and a wide base of knowledge are necessary. A number of conceptual models have been used to meet these conditions and have guided the research presented in this thesis.

First, the translational research cycle model modified for the use in sport injury prevention has been used as the primary framework in this thesis to outline the process of translating evidence into practice (Figure 7.1). The first part of this thesis relates to steps 3-5 of the modified research cycle. Two systematic reviews are presented, aimed at gaining insight in intervention strategies used in sport injury prevention studies (Chapter 2) and identifying essential elements of neuromuscular training (NMT) as an effective intervention to prevent ankle sprains (Chapter 3). These reviews aimed at providing guidance in developing effective and useable interventions, and as such strengthen the translation and implementation of the available evidence to broad practice. The second part of this thesis contributes to steps 6 and 7 of the translational research cycle, that is, the implementation and evaluation of preventive interventions in practice. Three interventions, using different intervention strategies, were implemented and evaluated at a national level in the Netherlands as part of (inter)national policies on sport injury prevention. The need for additional research in this field has been previously emphasised. The first two steps - identifying the extent of the sport injury problem, and establishing the aetiology and mechanisms of sport injuries - were not part of the research presented in this thesis.
Figure 7.1 The translational research cycle modified for the use in sport injury prevention [21, 22]; the research objectives addressed within this thesis relate to steps 3 - 7

Furthermore, a modified version of the original Haddon matrix has been used to identify and categorise 20 potentially relevant intervention strategies for the prevention of acute sport injuries (presented in Table 2.3) [36, 37]. Finally, indicators used in process evaluations to assess the public health impact of interventions were derived from the RE-AIM Framework, identifying five interacting dimensions (i.e. reach, effectiveness, adoption, implementation and maintenance of the intervention) [24, 323].

Main findings

Uneven distribution of intervention strategies used in sport injury prevention studies

Using a modified version of the Haddon matrix, the results in Chapter 2 provide valuable insight into the extent of the evidence base of sport injury prevention studies for 20 potential intervention strategies. This review showed that interventions used in sport injury prevention studies primarily targeted behavioural modifications in individuals, most often through training programmes aimed at building individuals’ capacity before the injury event to reduce the injury risk (e.g. improved physical fitness, skills and techniques). In contrast, research related to some specific intervention strategies is underrepresented, that is, only a limited number of studies evaluated the preventive effect of rule and regulation changes, contextual modifications, education, and psychological or cognitive skills training. Additional research is necessary to build on the current evidence regarding the effect of such intervention strategies to broaden the evidence base for implementation efforts. This is especially true for rule and regulation changes and contextual modifications as, in general, these strategies have the potential to reach and affect large populations (i.e. targeting a group or society level, based on an ecological approach to injury prevention) [37], and are found to be more effective in injury prevention
compared to intervention strategies that predominantly target behavioural modifications at an individual level[33, 37, 38].

**Context-specific intervention strategies**

Although a range of intervention strategies should be considered to support and strengthen sport injury prevention efforts in practice[33, 37, 38], it is important to realise that not all strategies are equally appropriate for all sports, injury types and/or sport settings. From Chapter 2 it can be concluded that differences found in intervention strategies used in sport injury prevention studies can be related to the nature of the sport, and the aetiology and risk mechanisms of injuries under study. Nonetheless, lessons can be learned from strategies used within different sport injury contexts.

**Key intervention components identified**

In Chapter 3 a systematic review and meta-analyses are presented on the prevention of ankle sprains through the application of neuromuscular training (NMT) programmes, aimed to identify essential ‘key’ intervention components. NMT programmes are effective in preventing recurrent ankle sprains[224, 225, 228]. However, available evidence indicates that compliance with these evidence-based programmes is low[78, 239], which can significantly affect study outcomes[249, 314]. Identification of essential elements of evidence-based interventions can facilitate intervention adaptations that may result in increased compliance without impacting results. Based on Chapter 3, a key component of NMT in preventing ankle sprains is balance training, irrespective of the use of balance boards. Both single-component (i.e. balance training alone) and multi-component interventions are effective in reducing ankle sprains. Relying on these study outcomes, the type of intervention most fitting to the context should be chosen for implementation efforts. This substantiates the significance of an increased insight in the working mechanisms of effective interventions for implementation efforts.

**Intervention strategies: from evidence to practice**

*Effectiveness of rule modification in sport*

Chapter 4 evaluates the preventive effect of rule modification as an intervention strategy. The shinguard law made the use of shinguards compulsory in football (i.e. soccer) matches for all amateur players in the Netherlands from the 1999/2000-season onward. Data covering 25 years of continuous registration (1986-2010) of soccer injuries treated at Emergency Departments of Dutch hospitals were used to evaluate the effect of this rule change. Time trend analyses showed that the incidence of lower leg soccer injuries decreased significantly following the introduction of the shinguard law, whereas the incidence of all other soccer injuries did not. These results strongly suggest the relevance of rule and regulation changes as an intervention strategy to prevent sport injuries. However, as rule and regulation changes generally apply to all players involved within a specific sport or setting, the potential advantages and disadvantages of rule modification aimed at preventing sport injuries should be well considered. This includes, for instance, whether a rule modification has a potential preventive effect for all players concerned, and whether it affects other aspects of the game that are not the object of the modification[208].
Health communication for changing preventive behaviour

Chapter 5 describes the effectiveness and reach of a nationwide intervention to increase voluntary helmet use in Dutch recreational skiers and snowboarders (DRSS). A prospective single-cohort study was conducted using online questionnaires for data collection before and after the intervention season. Study results showed a significant positive association between exposure to the intervention and self-reported helmet use in DRSS, with differences found between specific subpopulations. However, perhaps due to the lack of internal validity of the questions used, no significant associations were found between intervention exposure and any of the (self-reported) determinants of helmet use (i.e. knowledge, perceived knowledge, risk perception, attitude, social support and intention to helmet use). The intervention consisted of multiple components, implemented locally within the ski hall setting and nationally using health communication elements. Both implementation levels proved to be of value to reach our target population. Within the field of injury prevention, the contemporary use of various intervention elements that impact at multiple levels (i.e. influencing factors at an individual, group, and (inter)national level) is recommended, as it may be more effective than preventive measures affecting one level only.

eHealth as a practical tool

The third evaluation study assessed the implementation effectiveness of a Dutch mobile application including an evidence-based NMT programme to prevent recurrent ankle sprains (i.e. the ‘Versterk je enkel’ app) using the RE-AIM Framework (Chapter 6). The public health impact of the app depends on a large-scale implementation, and on compliance with the embedded programme. While the use of eHealth in general and mHealth in particular (through the use of mobile applications) is considered a practical tool for the dissemination of sport injury preventive interventions, the number of app downloads was low compared to the annual number of ankle sprains due to sport participation in the Netherlands. Current figures substantiate these findings with a mean reach of 4% within the target population since app release to date (September 2011 up to December 2016; VeiligheidNL, personal communication, 2017).

Although the app was valued for its use by the target population, compliance with the embedded programme was low. The low compliance was in line with previous findings. Increased insight in users’ perspectives (e.g. needs, wishes and possibilities) related to the app’s characteristics, its daily use, and the embedded programme may be essential to increase compliance. Convenience in use, for instance, has found to be essential for (prolonged) health app use in daily practice. The ‘Versterk je enkel’ app had been adapted based on information through the process evaluation, and further adjustments may be wanted. Moreover, the study results strongly indicate the need for targeted implementation efforts to ensure large-scale adoption and correct use of a mobile application.

A recent study added valuable information, indicating that both the ‘Versterk je enkel’ app and traditional, written materials using the same NMT programme showed similar effectiveness in terms of intervention compliance and incidence rates of self-reported ankle sprains. This allows the target population to choose their preferred method, which may increase use of and compliance with the NMT programme.
Methodological considerations

Methodological strengths and limitations of the individual studies have been described in the previous chapters. In addition, some limitations that are inherent to the methods used need to be discussed and emphasised when interpreting the overall results. This includes issues related to systematic reviews, study designs used in sport injury prevention studies, and the evaluation of nationwide interventions.

Systematic reviews

The strength of the results of a review depends on a systematic approach to identify all relevant published papers, and on the methodological quality of individual studies included in the review to minimise bias [334]. Both reviews included in this thesis used a systematic approach aiming for inclusion of all relevant studies (Chapters 2 and 3). Studies were considered for inclusion if the study design included a control group or a control condition, and if data were registered prospectively. Consequently, both intervention studies and observational studies were included. Inherent to the study design applied, the included studies represent different evidence levels and risks of bias [41].

As the primary aim of the first review (Chapter 2) was to identify and categorise sport injury prevention studies by intervention strategy used, risk of bias in individual studies was not assessed (i.e. no assessment of the methodological quality of relevant studies). A comparable approach has been used in previous systematic reviews aimed at providing an overview of published sport injury prevention studies [25, 30]. The second review (Chapter 3), evaluating the effectiveness of NMT to prevent ankle sprains in a sporting population, did assess the methodological quality of individual studies. A modified checklist was used to consider all possible sources of bias and to introduce more variability in the quality score. Not all criteria could be assessed for non-randomised controlled trials (non-RCTs) and the maximum quality score was adjusted accordingly. Although the use of this modified checklist allows for the inclusion of different study designs in the meta-analyses, attention should be given to the fact that similar quality scores (presented as a percentage of the maximum attainable score) do not imply similar strength of results for all individual studies. Consequently, both differences in methodological quality score and in study design need to be considered when interpreting individual study outcomes and pooled effect estimates regarding the effectiveness of preventive measures.

In Chapter 3 a graph is introduced to provide a full visual overview of all relevant studies included in a meta-analysis (Figure 3.2). This graph displays the preventive effect of individual studies related to the methodological quality score and study design used. By providing this overview, preventive effects of NMT were found independent of study quality and study design. It is in general recommended that ‘low quality’ studies are excluded from meta-analyses to reduce heterogeneity through risk of bias and to increase validity of the results [231]. However, meta-analyses need to balance risk of bias with precision and use an arbitrary cut-off score to distinguish ‘low-quality’ from ‘high-quality’ studies [230, 231]. The graph proposed in Chapter 3 can provide insight into the consequences of applying a specific cut-off score, by showing the number of studies excluded together with their outcomes.
Study designs used in sport injury prevention studies

Relying on the results of the systematic review presented in Chapter 2 non-RCTs have been used extensively in sport injury prevention studies, especially in studies on the effectiveness of rule and regulation changes and contextual modifications (Figure 2.2). Although an RCT is considered the gold standard for establishing the effectiveness of preventive interventions \[40-42\], other study designs (e.g. pretest-posttest designs and interrupted time series) appear to be valid options when inclusion of a control group is not feasible, for instance, in case of rule modifications and policy interventions implemented at an (inter)national level. Systematic reviews are generally used to support decision making in the development of preventive interventions and strategies for sport injury prevention in practice \[^{334}\]. If only RCTs would be considered for inclusion in such reviews, a wide base of relevant knowledge remains unavailable for practice.

Evaluating nationwide interventions

As we evaluated nationwide interventions in real-world sport settings, implemented as part of (inter)national policies on sport injury prevention (Chapters 4, 5 and 6), we were confronted with limitations in available study designs to evaluate the effectiveness of these interventions. Exposure to the intervention was not controlled by the researchers, and randomisation and inclusion of a proper control group was therefore not feasible. Consequently, no conclusions can be drawn regarding the causal effects of these interventions on the outcome measures under study, that is, incidence of lower leg football injuries (Chapter 4), determinants of helmet use and actual helmet use (Chapter 5), and the implementation of an NMT programme to prevent ankle sprains through app use (Chapter 6). Instead, we established associations between intervention exposure and outcome and controlled for possible confounders, using statistical analyses and deductive reasoning to determine whether factors other than the implementation of the intervention could have affected our study outcomes. Information on the five RE-AIM dimensions is considered essential to understand why and how an intervention has worked or had limited effects within a specific target group and sport setting \[^{19, 24}\]. These dimensions were evaluated based on self-reported data of study participants (Chapters 5 and 6). However, to our knowledge, no data are available that have monitored these aspects during and after the implementation period of the shinguard law (Chapter 4). The question remains to what extent in this latter study relevant stakeholders (e.g. individual players, coaches and referees) actually complied with this new regulation.

The intervention programmes presented in Chapters 5 and 6 were evaluated by researchers who contributed to the intervention development as well. This is not unusual in studies evaluating the effect of public health interventions. In a recent publication, de Winter et al. \[^{335}\] stated that the majority of studies (84%) evaluating health interventions for youth in the Netherlands were performed by researchers involved in the intervention development. They argued that this meant that researchers were acting as their own judge and jury, and that this could lead to more positive outcomes. This potentially confounding factor was remedied by including independent researchers in the studies presented in Chapters 5 and 6. However, it should be noted that, in our experience, involving the developers of interventions in the evaluation process results in a more comprehensive evaluation.
A need for subgroup analyses

Where possible, subgroup analyses should be used to increase insight into the working mechanisms of effective interventions and into subgroups that benefit (most) from implementing such interventions. For instance, essential intervention components and contexts of NMT to prevent ankle sprains have been identified using meta-analyses (Chapter 3). Subgroup analyses also proved to be of value to assess the effectiveness of mandatory shinguard use to prevent lower leg soccer injuries (Chapter 4), and to identify subpopulations that benefit (most) from a nationwide intervention aimed at increasing helmet use in DRSS (Chapter 5). However, we came across some limitations in applying subgroup analyses to evaluate essential components of this latter intervention. As the aim of the evaluation study was to evaluate the effectiveness of the nationwide intervention as a whole in a real-world sport context, exposure to the intervention (i.e. to one or more intervention components) was not controlled by the researchers. As such, our study design was not suited to unravel the effect of individual components on the outcome measures. Additional research is necessary to identify intervention components that contribute most to the targeted behaviour change, and as such develop more efficient interventions.

Implications

Implications for practice

Apply available evidence in practice

The public health impact of evidence-based interventions depends on effective implementation within the sport injury context. Relevant questions that need to be answered when developing, implementing and evaluating interventions are (i) whether the embedded preventive measure is evidence-based, and (ii) whether the intervention strategy is effective to translate and implement available evidence to broad practice, and as such reach the target population and change their preventive behaviour.

Relying on the results of both reviews presented in this thesis, a large evidence base is available on preventive interventions that predominantly target behavioural change on the part of individual athletes (i.e. strategies at an individual level). This evidence, based on scientific research, is available to be applied in daily practice. Relevant stakeholders (e.g. health professionals, sport federations, policy makers) have the opportunity and responsibility to use the available evidence as an essential starting point when developing and implementing sport injury preventive interventions. However, the available evidence is not absolute. Additional information is necessary to make a thorough decision on what strategy to use for the implementation of sport injury prevention in daily practice, including information about the cost-effectiveness and feasibility of interventions in daily practice [33, 216].

Include target populations

As effective implementation relies on the broad support and behaviour change from the target population and relevant others (e.g. coaches, referees, sport clubs) to adopt and use evidence-based preventive measures [20, 24, 218], it is important for relevant stakeholders to consider the needs, wishes, possibilities and demands of these target populations when developing and implementing a preventive intervention. This requires knowledge on the current preven-
tive behaviour and its determinants, and on potential facilitators and barriers for the uptake of preventive measures within a specific sport injury context \[20, 24, 32, 216\]. Relevant information should be gathered, preferably through active involvement of the target population and relevant others within the developing process of interventions, and through process evaluations among these groups. This emphasises the need for additional research in the field of intervention evaluation.

**A call for higher-level intervention strategies**
From a public health perspective, evidence-based preventive measures should be implemented in such a way that large populations can be reached and affected. This argues for the implementation of so-called higher-level intervention strategies, that is, interventions targeting a group or society level. This, in general, includes the application of rule and regulation changes, policies, product and other contextual modifications. Although the evidence base of these strategies is lagging compared to strategies that predominantly target a behaviour change on the part of individual athletes (i.e. strategies at an individual level), the available evidence is promising and provides new opportunities for sport injury prevention. Stakeholders should consider the feasibility of implementing such strategies more frequently, and should call for supplementary studies to evaluate their effectiveness. However, as not all intervention strategies are equally relevant for all injuries and sport injury contexts, the preferred option must be chosen considering multiple contextual factors within a specific target group and sport setting \[17, 19, 35\]. Again, this underlines the relevance of active involvement of the target population and relevant others within the developing process of interventions.

**Implications for future sport injury prevention research**
Based on the results presented in this thesis, some challenges and opportunities for future sport injury prevention research can be identified. These challenges and opportunities relate to the questions raised in the introduction, whether (i) sufficient evidence is available regarding each step of the translational research cycle (Figure 7.1), and whether (ii) the available evidence base on sport injury prevention can effectively be translated to a practical context.

**A need for a more comprehensive evidence base on sport injury prevention**
Potential gaps in the knowledge base on sport injury prevention have been identified (Chapter 2). This especially applies to studies on the effectiveness of higher-level intervention strategies, including rules and regulation and contextual modifications aimed to prevent sport injuries. These knowledge gaps provide new opportunities for sport injury prevention research. Next, with respect to strategies primarily targeting behavioural changes on the part of individual athletes, additional studies are warranted on the preventive effect of education, and psychological and cognitive skill training. In general, a need for additional research should not only be based on existing gaps in the knowledge base on sport injury prevention, but should also originate from needs and knowledge gaps experienced in daily practice. Stakeholders can identify relevant research questions within a specific sport injury context. Combined efforts of science and practice are necessary to identify relevant research questions that provide new opportunities for effective sport injury prevention in daily practice.
7 General discussion

**Extensive use of available evidence**

A wide evidence base on sport injury prevention is available for implementation efforts. The available evidence should be used more extensively to identify components of effective interventions that impact most on sport injury prevention. Similarly, specific subpopulations and sport settings can be identified that benefit most from a specific intervention. This yields valuable information about the working mechanisms of effective interventions. Through this approach, evidence can be translated into effective and usable interventions that can be implemented in real-world sport settings, which may result in increased adoption and high compliance [22]. This approach has been applied to NMT programmes aimed at preventing recurrent ankle sprains using meta-analyses (Chapter 3), and can potentially be applied to many more areas of sport injury prevention.

**Alternative study designs**

Non-RCTs can be valid options to evaluate the effectiveness of sport injury preventive interventions. This especially applies to the evaluation of interventions implemented at an (inter)national level, and strategies targeted at rule and regulation changes and contextual modifications in sport. Alternative forms of RCTs have been suggested in literature, including stepped wedge designs (in which an intervention is sequentially implemented if randomisation is possible) and Solomon four group designs (to control for the effect of a pretest) [41, 214]. The use of these study designs should be considered in future sport injury prevention research.

**Real-world evaluation studies**

The effect and process evaluations included in this thesis targeted outcome measures at the level of the target population (i.e. the end user of preventive measures). Additional evaluation studies are necessary, also including the level of relevant stakeholders to gain insight in why and how an intervention was (not) effective in real-world sport settings. Increased insight in reasons for (the lack of) compliance with effective interventions is especially warranted, as illustrated in Chapter 4 by the study on the implementation effectiveness of an evidence-based app. As the public health impact of interventions relies on effective implementation and sustainability at all relevant target intervention levels (e.g. at an individual, group, or sport association level), it is essential to include all target intervention levels when evaluating interventions [24, 336].

**Overall conclusion**

Actual prevention of sport injuries in real-world sport settings requires large-scale implementation of evidence-based preventive measures. Actual prevention relies on a sustained change in the preventive behaviour of individuals in order to adopt and properly use such measures. Study results indicate that a range of potentially relevant intervention strategies is available to support and strengthen implementation efforts. However, not all strategies are based on sufficient evidence or are relevant for all sport injury contexts. Results showed that the majority of evidence targeted behavioural modifications in individuals. Additional research is needed to build on the evidence base for specific intervention strategies, including rule and regulation changes, policies, product and other contextual modifications. Although the evidence base of these strategies is lagging compared to other strategies, the available evidence is promising and
provides new opportunities for sport injury prevention. This is especially true as these strategies rely less on behavioural modification on the part of the individual athlete and have the potential to reach and affect large populations. Moreover, additional analyses can yield information on essential intervention components and contexts that can be translated into more usable interventions without impacting effectiveness. Joined efforts of science and practice are needed to understand the working mechanisms of effective interventions, support effective implementation through evidence-based interventions that are adopted and complied with, and to stimulate practice-driven research that fits the needs of specific sport injury contexts.