The effectiveness of an e-health tennis-specific injury prevention programme. A randomised controlled trial in adult recreational tennis players

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Abstract

Background: Despite reported injury rates of up to 3 per 1000 hours exposure, there are no evidence based prevention programs in tennis.

Purpose: To evaluate the effectiveness of an e-health prevention programme for reducing tennis injury prevalence.

Study design: Two-arm, researcher-blinded randomised controlled trial

Methods: Adult tennis players of all playing levels were randomized in an unsupervised programme lasting 12 weeks (TennisReady group) or control group. The primary outcome was the overall injury prevalence over a 16-week period, measured at two-weekly intervals with the Oslo Sports and Trauma Research Centre questionnaire. Estimates for the primary outcome and associated 95% confidence intervals was obtained using generalized estimating equation models. Secondary outcome scores included prevalence of substantial injuries, overall incidence, adherence and time-loss injuries.

Results: A total of 579 (83%) (TennisReady N = 286, control N = 293) participants were included in the primary analysis. The mean injury prevalence was 37% (95% CI) 33 to 42) in the TennisReady versus 38% (95% CI 34 to 42) in the control group (adjusted p-value 0.93). The prevalence of substantial injuries was 11% (95% CI 9 to 14) in the TennisReady versus 12% (95% CI 9-15) in the control group (p-value 0.79). Analysis of the secondary outcome scores showed no difference between groups. The mean prevalence between high (8%) and low (92%) adherent groups were respectively 32% (95%CI 23-44) and 37% (95% CI 33-42) (p-value 0.36).

Conclusion: Providing an unsupervised e-health tennis-specific exercise programme did not reduce the injury rates and should not be implemented.

Introduction

Tennis is a very popular sport with around 75 million active players worldwide [1]. Recent studies show that injury rates vary from 0.04 to 3.0 per 1000 hours played[2-5]. The majority of injuries in tennis are overuse injuries, such tendinopathy of the knee, elbow or shoulder (61%–80%) rather than acute injuries. [4-6]. The high proportion of overuse versus acute injuries is in contrast with previous reports[2] and demands new approaches towards injury prevention.

Despite high levels of evidence in favour of exercise-based prevention, predominantly in team sports[7 8], research in this domain for tennis players is lacking. In the absence of any evidence based prevention strategies in tennis[3], we developed a tennis specific exercised based prevention e-health programme[9] using the knowledge transfer scheme as a guideline[10]. The content of this programme was based on exercises from other exercise based injury prevention programmes[11-14].

The aim of this trial was to evaluate whether the TennisReady unsupervised e-health programme reduces the overall injury prevalence compared with usual care. The secondary aims were to evaluate incidence per 1000 hours of tennis exposure.

Methods

Design

The design was a two-arm, researcher-blinded block randomised controlled trial. We followed the Consolidated Standards of Reporting Trials.[15]. The study protocol was registered in the Netherlands Trial Registry.

Participants

Tennis players were recruited between February 2017 and September 2017 through social media, direct mail, newsletters and flyers at tennis events. Detailed information about the study procedure, participant rights and contact information for further questioning was available online. Eligible tennis players were invited to register online through a survey programme (LimeSurvey, LimeSurvey GmbH, Hamburg, Germany). On registration, online informed consent was obtained.

Tennis players were eligible for inclusion if they were at least 18 years of age, owned an IOS or android based smart device and were willing to perform an exercise programme at least twice a week. There were no exclusion criteria.

Trial procedure, randomisation and blinding

At the start of the study in May 2017, one author (OK) registered all eligible players who had already indicated that they would like to participate in a data management, survey and randomisation programme (CastorEDC, CIWIT B.V., Amsterdam, The Netherlands). After entry into the database, the players were block randomised in the ratio 1:1 using random blocks of sizes two, four and six. Players registering for participation after this first batch, were entered into the system each subsequent week. This meant that each following week, a new batch of players was randomized. Detailed description of randomisation and blinding procedure is presented in supplementary appendix A.

Injury registration

At baseline all participants received a baseline survey which recorded gender, weight, height and playing level (International Tennis number(ITN))[16] for both singles and doubles play (1-9, 1 being the highest playing level), number of years playing tennis, preferences for singles or doubles play, most frequently used court surface (clay, hardcourt, grass, carpet, all weather courts, multiple courts) and previous lifetime injuries.

The injury survey was sent at two-weekly intervals over a 16-week period. The injury survey registered the number of hours of tennis exposure, injury locations, injury types, time loss (number of days that players were unable to participate due to injury) and injuries on the modified Oslo Sports and Trauma Research Centre questionnaire4 16 (OSTRC). The OSTRC had been previously validly translated using a forward-backward procedure4. A detailed description of the OSTRC questionnaire is given in the supplementary appendix A

Intervention

The TennisReady prevention programme was systematically developed and co-designed with the end-users (tennis players) through a five-step approach guided by the Knowledge Transfer Scheme[10], and has previously been described in full detail. [9]. The program was available through a smartphone application (app) on Android and iOS. The app's content was available for download to enable off-line usage.

A detailed description of the 12 weeks, 7-10 minutes TennisReady programme is given in the supplementary **appendix B, Table S1-S4.** Briefly, TennisReady consisted of an on-court warm up programme with cardiovascular, neuromuscular and tennis-specific exercises. An off-court (at home) strengthening programme was available. All exercise regimes were made increasingly difficult every two weeks by increasing repetitions or by changing exercises for more complex ones. Players were free to choose between the on-court and off-court alternatives every TennisReady session. All players in the TennisReady group were requested upon entry to perform the on-court programme prior to each tennis session or, alternatively perform the off-court programme in order to attempt two exposures to the TennisReady programme per week.

Participants in the control group were instructed to continue their current warm up and tennis practice.

Outcomes

The primary outcome was the overall injury prevalence as measured with the OSTRC questionnaire over a 16-week period. A recordable injury was defined as any response above the minimal value on at least one of the four OSTRC questions[14] , if the score was not due to an illness.

Secondary outcomes were prevalence of substantial injuries and injury incidence density defined as the total number of injuries per 1,000 hours of tennis exposure. Substantial OSTRC injuries were defined as injuries leading to moderate or severe reductions in training, volume or performance, or a total inability to participate[14]. We reported injury incidence density and prevalence by anatomical location (ankle, knee, shoulder and elbow). Prevalence and incidence for substantial injuries were also calculated.

Finally, self-reported time loss and self-reported adherence (see **supplementary appendix C**) to the intervention were also included as secondary outcomes. Adherence was recorded per survey in five adherence categories (always, almost always, sometimes, never, not applicable) and per exposure category (game play, unsupervised practice, supervised practice). Adherence was then dichotomized into high adherence (always/almost always) and low adherence (sometimes/never/not applicable). In addition, a set of rules was created to summarize the adherence over the three exposure categories into "high adherence" or "low adherence" over all surveys. A more elaborate explanation is available in **supplementary appendix C.**

Sample size

We calculated that for a 50% reduction in period prevalence of overall injury from 0.24[17] to 0.12, α of 0.05 and β of 0.90, a sample of 230 participants per group were needed. Correcting for an estimated dropout rate of 30%, the sample size was set at 329 per group. Hence, we aimed to randomize at least 658 participants.

Statistical analysis

We used descriptive statistics to present the baseline characteristics, the results of the OSTRC survey and adherence in both the intervention and control group. We examined whether continuous variables were normally distributed by visually examining histograms. We described normally distributed continuous variables using the mean and standard deviation, non-normally distributed continuous variables using the median and lower and upper limits of the interquartile range and categorical variables using counts and percentages. We compared the intervention and control groups' baseline characteristics using unpaired t-tests, Mann-Whitney-U and Fisher exact tests, as appropriate.

The analyses of the primary and secondary outcomes were performed based on an intention to treat principle, available data and a joint analysis of the primary outcome and missing data process. For the modified intention to treat analyses, a participant was considered available for the analysis of the primary outcome if the baseline questionnaire and at least one follow-up survey had been completed.

For the primary outcome, injury prevalence were calculated as the number of players reporting an injury divided by the total number returned questionnaires per injury survey instance[14]. Estimates for the injury prevalence over the whole period and associated 95% confidence intervals were obtained using generalized estimating equations (GEE) with a binomial distribution and logit link function. A similar GEE model was used to examine the association between intervention group and the missing data process. To correct for potential confounders, we performed an additional GEE analysis on the injury prevalence correcting for previous injury[18], multiple court surface use versus non-multiple court surface use[6] and gender[19]. These three confounders have been previously identified in a review on risk factors for injuries in tennis players[3] In order to test the robustness of our analysis, worst case, best case and complete data analyses were performed (see online supplementary appendix C). For the secondary outcome testing, see online supplementary appendix C.

Results

Participants and follow-up

Between May and September 2017, 1084 tennis players expressed an interest in participating in the trial. In total 700 met the inclusion criteria, of these 349 were randomly assigned to the TennisReady trial arm and 351 to the control arm. A total of 121 participants (17%) (TennisReady = 63, control = 58) completed none of the injury surveys and thus were unavailable for analysis. Hence, a total of

579 (83%) (TennisReady group = 286, Control group N = 293) participants could be included in the analysis of the primary outcome. Seven participants (1%) (TennisReady group = five, control = two) withdrew from the trial after having completed at least one survey; their incomplete data was used for the modified intention to treat analysis up to their withdrawal**.** Complete data was available for 152 participants (22%) (TennisReady = 60, controle = 92). **Figure 1** shows a flow chart of the entire recruitment process. Supplementary **appendix D , figure S1** illustrates the number of participants included in the study over time.

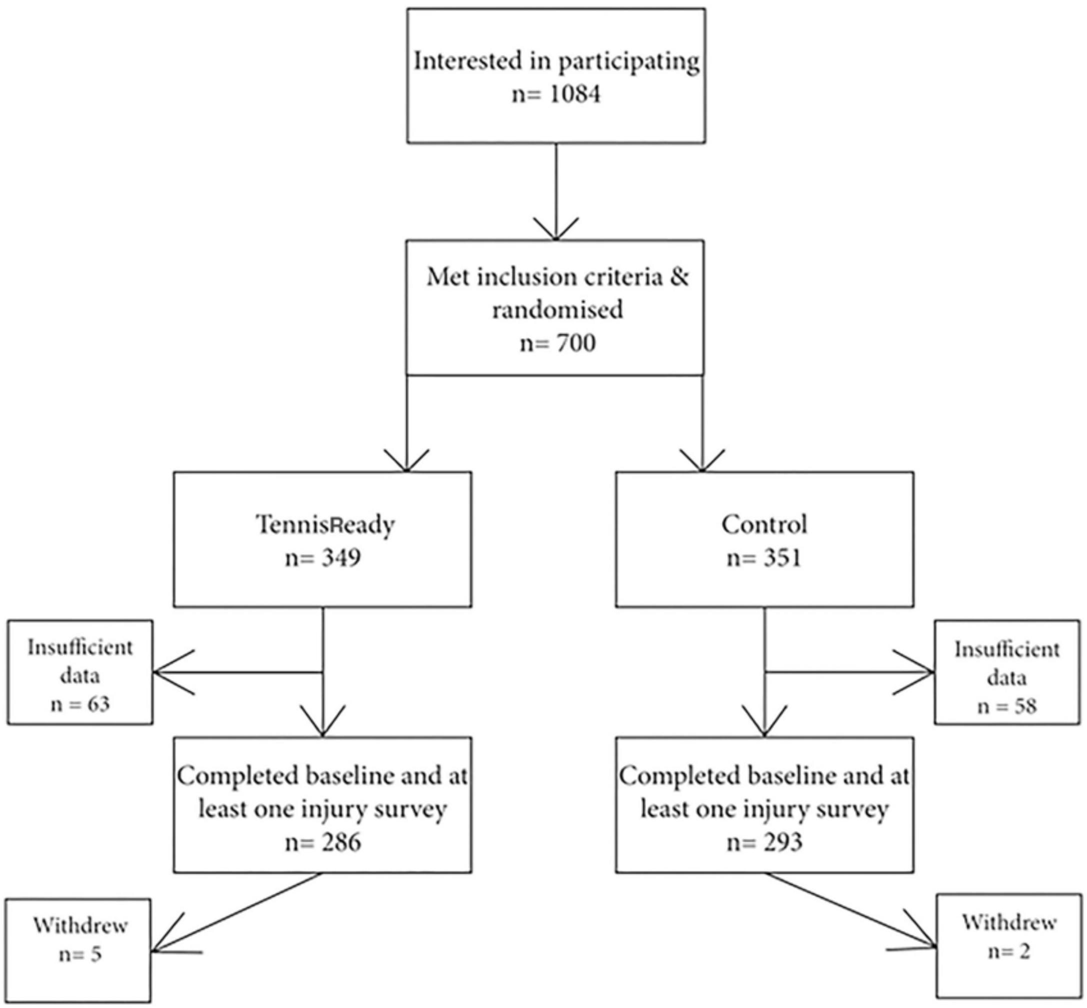

Figure 1. Flowchart of the study procedure

The participant baseline characteristics were similar between the groups (Table 1). The mean age was 41 years (standard deviation (SD) 12) in the TennisReady group versus 42 years (SD 13) in the control group. All participants were recreational tennis players with a median single player level ITN of 7 in both groups (IQR 5-8 and 6-8 for TennisReady and control respectively). There were 157 (55%)

women in the TennisReady group and 149 (51%) in the control group. At baseline, >80% of participants in both groups had experienced a previous injury.

Table 1: Baseline characteristics

Characteristic	TennisReady n = 286	Control n= 293
Age in years (SD)	41 (SD 12)	42(SD 13)
Number of females (%)	157 (55%)	149 (51%)
BMI in Kg/m^2 (SD)*	24.7 (SD 3.5)	24.6 (SD 3.5)
Playing level singles range 1-10** (IQR)	7 (IQR 5-8)	7 (IQR 6-8)
Playing level doubles range 1-10** (IQR)	6 (IQR 5-8)	6 (IQR 5-7)
Percentage of lifetime previous injury	82% (n= 234)	85% (n= 248)
Number of participants reporting court use		
Clay (%)		
Hardcourt (%)	114 (40%)	112 (38%)
Grass (%)	5 (2%)	4 (1%)
Carpet (%)	36 (13%)	40 (14%)
All weather (%)	7 (2%)	2 (1%)
Multiple courts (%)	102 (36%)	103 (35%)
	22 (8%)	32 (11%)

* BMI: body mass index; due to incorrect survey inputs BMI could only be calculated for 291 controls and 284 TennisReady subjects. ** Medians with interquartile range, IQR = interquartile range, SD = standard deviation, Kg = kilogram, m = meter

Response rate and exposure

As illustrated by **figure S2** of the supplementary **appendix D** the response rate decreased over the 16 weeks period from 98% (n=281) and 97% (n=285) (TennisReady and control respectively) to 34% (n=96) and 48 % (n=139) respectively. Sixty participants (17%) in the intervention group and 92 (26%) in the control group completed all surveys.

A total of 22,076 exposure hours were recorded (10,366 hours for TennisReady vs 11,710 hours for control) over the period of 16 weeks, with corresponding median of 27 hours (IQR 13-51) per player in the TennisReady group versus 32 (IQR 21-55) hours of exposure per player in the control group. This difference was statistically significant (p value < 0.01).

Primary outcome

The overall injury prevalence was 37% (95% CI 33-42) in the intervention group versus 38% (95% CI 34-42) in the control group. Figure 2 illustrates the injury prevalence over time. After correcting for previously defined confounders, the adjusted p-value was 0.93 (Table 2). The sensitivity analysis showed that the outcome of the primary analysis did not change in the outcome effect for the worst case and complete data scenario (Table 2). The best-case scenario was in favour of the TennisReady group although confidence intervals overlap.

Table 2: Primary outcome scores (prevalence) and sensitivity analysis with 95% confidence intervals

Outcome	TennisReady n = 286	Control n = 293	p-value
Overall injury prevalence	37 % (33-42)	38 % (34-42)	0.93*
Sensitivity analysis			
Best case	21 % (18-23)	25 % (22-28)	0.04
Worst case	63 % (60-67)	58 % (55-62)	0.06
Complete data	28 % (22-35)	36 % (29-43)	0.12

*** corrected for confounders**

Figure 2: Overall injury prevalence (open symbols) and substantial injuries revalence (filled symbols) in the TennisReady (black lines) and control (dotted lines) at 2 weeks interval over the 16 weeks period.

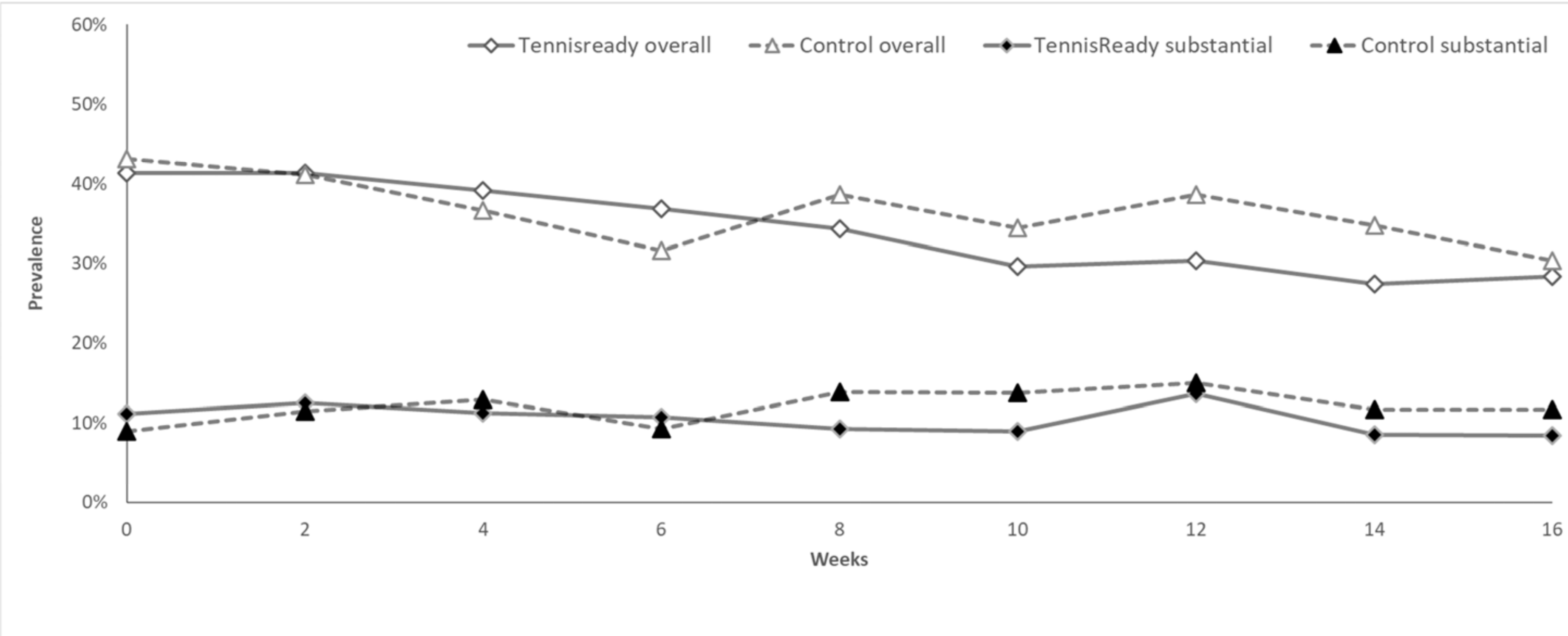

Table 3. Secondary outcome scores with 95% confidence intervals

Outcome	TennisReady n = 286	Control n = 293	p-value
Prevalence			
Ankle	2 % (1-4)	2% (1-4)	0.68
Knee	6 % (4-8)	5 % (4-8)	0.88
Shoulder	4 % (3-6)	5 % (3-7)	0.57
Elbow	3 % (2-6)	3 % (2-5)	0.78
Substantial injuries	11 % (9-14)	12 % (9-15)	0.79
Injury incidence*			
Overall	25.4 (22.5-28.7)	24.4 (21.8-27.4)	0.66
Ankle	1.5 (0.9-2.5)	1.3 (0.8-2.1)	0.60
Knee	3.4 (2.4-4.7)	3.3 (2.4-4.5)	0.95
Shoulder	2.3 (1.5-3.4)	2.5 (1.7-3.6)	0.81
Elbow	1.4 (0.9-2.4)	2.0 (1.4-3.1)	0.29
Substantial injuries	6.7 (5.3-8.5)	7.2 (5.8-8.9)	0.71
Time loss per injury in days	5.6 (5.4-5.9)	6.3 (6.0-6.6)	0.00

* incidence per 1000 hours of tennis exposure.

Secondary outcomes

Incidence and substantial injuries

The overall injury incidence was 25.4/1000 hours tennis exposure (95% CI 22.5-28.7/1000 hours) in the TennisReady group versus 24.4/1000 exposure hours (95% CI 21.8-27.4/1000 hours) in the control group. The prevalence of substantial injuries was 11% (95% CI 9-14) in the TennisReady group versus 12% (95% CI 9-15) in the control group (p-value 0.79) (Table 3, Figure 2). Poisson corrected GEE showed no difference between groups. No differences were found for location specific incidences (Table 3).

Time loss injuries

The mean time loss per injury was 5.6 days (95% CI 5.4-5.9) in the TennisReady group and 6.3 (95% CI 6.0-6.6) days in the control group (Poisson corrected GEE model $p < 0.01$). We did not consider this difference to be clinically relevant.

Adherence

For the two weeks adherence scores during the intervention period, 110 questionnaires out of 1401 (8%) met the algorithm for high adherence. When comparing the algorithmically selected high adherent group to the low adherence group, the mean prevalence was respectively 32% (95%CI 23-44) and 37% (95% CI 33-42). This was not statistically significant ($p = 0.36$). When comparing the algorithmically selected high adherent group, the mean prevalence was respectively 32% (95%CI 23-44) for the high and 38% (95% CI 34-42) for the control group, with no statistical significant difference between these groups ($p = 0.63$).

Discussion

Our randomized controlled trial involved almost 600 non-professional tennis players. We showed that providing a 7-10 minutes e-health tennis-specific unsupervised prevention programme of 12-weeks was not effective for reducing injury prevalence and incidence.

Comparison with other studies

This study was the first randomized controlled trial to evaluate an exercise- based prevention strategy in tennis[3], which prevents comparison with other tennis prevention studies. Exercise- based prevention strategies have previously been investigated in both team and individual sports[7 8 20-22] with varying results. In these studies, coach-supervised programs in team sports (e.g. football, handball) were often successful [7 8]. Unsupervised exercise based prevention programmes have been found effective in reducing the number of recurrent acute ankle injuries[12]. No other unsupervised exercise programmes in individual sports have been successful in significantly reducing injury rates[7 20-22]. Unfortunately, our results are in line with these previous findings.

Adherence

In contrast to some other sports, a warm-up is generally not performed by recreational tennis players[9]. Nevertheless, during the systematic development of our intervention, 75% of the respondents reported to be motivated to perform warm-up exercises at least twice a week[9]. In our controlled research setting, the overall adherence was not optimal. We cannot exclude that the effect of the intervention was influenced by lack of adherence with the intervention programme.

The definitions of the degree of adherence (high versus low), methods (coach versus player reporting) and frequency of measurements differ among studies[23]. We categorically defined a high player adherence as performing the exercises "always" or "nearly always" for at least half of their exposure types, which might be considered as a relatively high threshold. In a comparable multi-modal intervention program in Norwegian amateur youth football players (FIFA 11+),[24] a high adherence threshold was defined as performing the exercises at least once a week (despite the recommended frequency of twice a week). They reported high player adherence in only 47%. Similarly, in professional Norwegian handball[14], a relatively low percentage of high player adherence was scored (53%; threshold 3/week). As both Norwegian studies showed positive outcomes, despite less than 1 out of 2 participants meeting the criteria for high adherence, it remains unknown if the negative results in our study can be contributed exclusively to our reported adherence rates.

Content, delivery, receipt and quality of the intervention

Another explanation for the absence of a preventive effect might be that the content, delivery, reception and/or quality of the performance of the exercises were ineffective. Although the content of our programme was based on other effective multimodal exercise-based prevention schemes in sports, [9 11-14] there is no evidence that for any of the exercises by itself was effective in reducing injuries. In all previously used programmes [11-14] a combination of different exercises was used, often with a specific focus on lower or upper extremity injuries only.

The delivery was through an App based program, which included offline videos and written instructions in order to improve the delivery of the content. However, no push messages, in case of non-use, were integrated and the app did not include a feedback feature. This might have influenced the reception of and adherence to the intervention. The main limitation of strictly App based interventions might be the absence of supervision by a coach (quality control). This could have resulted in poor execution of the exercises rendering them ineffective.

Strengths & limitations

We are the first to publish a large scale randomised controlled trial investigating injury prevention in tennis players. An important strength of our trial was that the program was developed using a systematic approach guided by the Knowledge Transfer Scheme (KTS)[9 10]. Through this bottom-up approach, the target users were involved throughout the complete process of the development of the intervention. The unsupervised (less controlled) intervention reflected daily practice of predominantly unsupervised exposure at a recreational level, which strengthens the external validity. The bi-weekly validated OSTRC questionnaires enabled registration of all acute and overuse injuries without restriction to time-loss injuries only, resulting in a larger number of reported injuries and increased power of the study.

Due to the nature of the intervention, blinding the participants was not possible. We did attempt to optimize blinding of the assessors as much as possible and all involved remained blinded while interpreting the results. In an attempt to assure unbiased interpretation of the results, the raw data was analysed and recorded by an independent statistician. The code was broken once the authors agreed on the interpretation of the results.

Due to the unsupervised and less controlled setting, we were unable to verify completion of each single exercise (within session adherence) and quality of the exercises. Random visits (in vitro observations, fidelity observations) would have given us more information about the quality of the performed intervention.

Another limitation was the mean response rate of completing the biweekly questionaires 56-66%, which decreased over time to 17 (intervention)-26 (controls)%. This leaves room for attrition. We have attempted to reduce this risk by performing best and worst case scenarios on the data which showed no differences.

In absence of well-defined golden standard[23], it was decided to categorically evaluate the adherence at player's level. Registration at player level of the number of completed exercise sessions per week, would have enabled quantification of adherence as a continuous variable (instead of categorical). Prior to the trial, we attempted to recruit tennis school trainers and create a supervised setting. However, due to insufficient responses, we were unable to achieve this and missed the unique chance to evaluate whether a supervised setting would have been associated with a higher adherence.

Recommendations for future interventions studies in tennis

We recommend trying to improve the adherence, content of the intervention and quality of the exercises. In future studies, potential improvement of adherence and superior exercise quality could be tested in a coach-based supervised setting. New studies might give more insight if Apps include the best practice for delivery and reception of interventions. Uniform adherence definitions, validated and reliable adherence measures are required for comparison within and between studies.

Should it change daily practice?

Considering the lack of effect, we do not recommend the use of similar unsupervised e-health injury prevention schemes in tennis players.

Conclusion

In its current form the unsupervised ehealth exercise program did not reduce the risk of tennis injuries. It questions the use of unsupervised e-health prevention programs in tennis and is not recommended for implementation.

Acknowledgments and disclosure

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Box: What are the findings?

Providing an e-health tennis-specific unsupervised exercise programme of 12 weeks, 7-10 minutes exercise program did not reduce the risk of tennis injuries.

Box: How might it impact on clinical practice in the future?

- **Our unsupervised e-health prevention program should not be implemented in recreational tennis.**
- **We suggest evaluating the program in a coach-based supervised setting.**

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