Effects of gluteal muscles strengthening on lower-limb injuries in male professional handball players: a preliminary study

Running Head: Injury prevention in handball

ABSTRACT

This study aimed to analyze the effects of a strength training injury-prevention program (STIPP) on injuries associated with weakness of the gluteal muscles for professional handball players. Twenty-seven professional Spanish male handball players from the same club, who competed at the Spanish Second National League level, participated in this study. The investigation was conducted over two consecutive seasons (2017-18 and 2018-19). The first season served as a control (n = 21) and the second season served as the experimental season (n = 20). The STIPP was conducted two times per week, for 32 weeks, during the in-season period. There were no significant improvements in injury incidence, pattern or type for the experimental season group compared to the control season group [injury rate ratio (IRR) = 1.47; 95% confidence interval (CI): 0.84-2.58; p = 0.17]. However, there was a meaningful reduction in the number and burden of lumbar injuries after the STIPP (IRR = 55.83; 95% CI: 0.11-89.01; p = 0.001). In addition, burden values (number of absence days / 1000h exposure) in all injury pathologies were lower during the experimental season compared with the control season. The STIPP focused on gluteal muscles could be effective in reducing the number and burden of lumbar injuries in professional handball players.

Keywords: team-sport; prevention; injury rate; strength training; burden.

INTRODUCTION

Handball is a collaboration-opposition team sport in which players are exposed to high physical condition requirements to perform high-intensity actions including jumps and multi-directional sprints (6,36). The rules of the game allow players to contact opponents in the defensive process (39) which produces situations in which handball players are susceptible to injury (42). Being injured results in negative consequences in sporting and economic terms, for players and clubs (28). In this sense, an injury generates traumatic effects for the athlete, including physical and psychological health issues, the potential loss of the entire season of sports participation, and the loss of sponsorship funding for elite athletes (32). High costs of treatment and sick leave are associated with injuries in professional-level sports (13).

In male elite handball players, the injury incidence has been estimated to range between 4.1 and 12.4 injuries/1000 hours exposure (33,34). Injury rates are greater during match-play (8.3-14.3 injuries/1000 hours) than training sessions (0.6-4.6 injuries/1000 hours) (3,38). Ankle, knee, thigh and lumbar injury incidence is high in handball players, with ligament sprains and muscle strains being common (33,34,38). Intrinsic and extrinsic risk factors, and injury mechanisms must be identified for handball players to help guide content of injury prevention programs to reduce the injury risk which is the main concern of the medical staffs of professional handball teams.

Given the impact of injuries in elite handball players and clubs, injury prevention programs have gained greater impetus as part of the player's daily training schedule. A meta-analysis (28) reported that strength training programs reduced sports injuries to less than one-third, and showed better results than proprioception, stretch or multicomponent training programs. Askling et al. (1) showed a significantly ($p = 0.05$) lower number of hamstring injuries (3 versus 10) in the 15 professional soccer players who performed a

10-week eccentric-strength training program compared to the 15 professional soccer players who did not do the program. After a 13-week (i.e., 25 sessions) Nordic hamstring training program, van der Horst et al. (20) found a significant ($p = 0.05$) reduction in hamstring injuries with only two in the experimental group of 309 male amateur soccer players versus 12 in the control group of 310 male amateur soccer players. Zouita et al. (45) did not observe any muscle injuries in 26 elite male junior soccer players after a 12-week strength training program containing traditional resistance training exercises (e.g., squat and bench press). Conversely there were 6 muscle injuries in the 26 elite male junior soccer players that did not do the 12-week strength training program. Despite the benefits shown in previous studies, there are no evidences about the preventive effects of strength-training programs in professional handball players.

The gluteal muscles (i.e., maximus, medius and minimus areas) are responsible for stabilizing the pelvis and controlling femoral adduction and internal rotation during functional activity (15). These muscles are one of the main contributors to force production in lower limb extension (27) and protectors of the ankle joint through the increase of its activity during sudden ankle inversions (41). The gluteal muscles plays an important role in handball movements that involve deceleration, stopping, and turning (19). In this sense, gluteal muscle weakness may contribute to lower extremity injuries (37) common to handball practice including lumbar injuries (24), hamstring injuries (14), illio-tibial band (ITB) syndrome (15), patellofemoral pain syndrome (PFPS) (11), anterior cruciate ligament (ACL) and other knee injuries (22) and ankle ligament injuries (16). Therefore, it seems necessary to develop specific conditioning programs for the gluteal muscles strengthening, and consequently, to reduce the injury risk in professional handball players.

Since it has been shown that handball players suffer a large number of injuries throughout the season and there are few investigations that examine the effects of preventive programs on this sport (44), without any of them focusing on the gluteal muscles, further studies that analyze the effects of preventive programs in handball players should be implemented. Therefore, the aim of this study was to analyze the effects of an injury-prevention strength training program (STIPP) on the injuries associated with the weakness of the gluteal muscles in professional handball players. It was hypothesized that a strength training program targeted on gluteal muscles and applied during all the in-season period would reduce the lower-limb injury incidence and burden in professional handball players.

METHODS

Experimental Approach to the Problem

A quasi-experimental study was conducted over two consecutive seasons. The first competitive season served as the control season, and the second season as the experimental season. The amount of physical training pre-season and during the season was similar for both seasons, with the difference being the type of strength training provided during the experimental season. All players performed 5-7 in-court training sessions and 2-3 group strength training sessions per week in both seasons.

(Figure 1 near here, please)

Subjects

Twenty-seven professional male handball players from the same club, who competed at the Spanish Second National League level, participated in this study (statistical power > 0.80) during two consecutive seasons (2017-18 and 2018-19). The study involved a squad

of 21 players during the first season (i.e., control) and a squad of 21 players during the second season (i.e., experimental). Fifteen (71.4%) of the players from the first season were also in the second season. Before inclusion in the study, participants completed a comprehensive medical and injury-history questionnaire. Players who were injured in the two months before the start of the control (1 player) and experimental (2 players) seasons were excluded from the study. The study was conducted according to the Declaration of Helsinki and was approved by the University`s Research Ethics Committee.

Experimental intervention - Strength training injury prevention program (STIPP)

The 32-week long-term and progressive strength training and injury prevention program (STIPP) was targeted to the gluteal muscles, because they are involved in decisive actions such as deceleration, stopping, and turning, during match play (19). In addition, handball players should strengthen gluteal muscles to enhance the stabilization of the pelvis and the control of the femoral adduction and internal rotation reducing the injury risk (15). The 64 sessions of 20-25 minutes each had at least 48 hours of rest between sessions. All sessions were supervised by the strength and conditioning specialist of the team, who provided feedback and advice for exercise execution. The STIPP was composed of three different exercise sequences, since this structure was recommended for time efficiency and stimulus variability (8,12). Sequences were designed to develop the gluteal muscles and included three strength-training exercise types (Figure 2) which involved active mobilization, strengthening and proprioception and progression steps (37,40). Exercises were selected according to their positive effects on the gluteal muscles (5,10,18). Progressive overload was applied during the intervention (Table 1).

(Figure 2 near here, please)

(Table 1 near here, please)

Injury exposure, incidence, burden and characteristics definitions

This study was conducted following the definitions and data collection procedures proposed for epidemiological studies by UEFA consensus (17). The date and exposure condition (training or match-play), the injury diagnosis characteristics, and time to return to play for each players injury were recorded by the team physiotherapist using a standardized questionnaire (17). Exposure was the time (in hours) both in training and match-play, during which the player was in a position to suffer an injury (32). Match-play exposure was calculated when the team analyzed in this study played friendly or official competition. Training exposure was calculated when the technical staff carried out in-court and gym training sessions. Training exposure was calculated individually, while match exposure was calculated as the number of total matches during the season times 1-hour times seven players. An injury was defined as "an injury that occurred during a scheduled training session or match that caused absence from the next training session or match" (17). A player was considered ready to return to play after an injury when he was given medical clearance to participate fully in team training and/or match-play. Injury types were coding following the Orchard Sports Injury Classification System (OSICS-10 codification) as in a previous epidemiological study with handball players (33). Only pathologies related with the gluteal muscles (i.e., lumbar injuries, hamstring injuries, ITB syndrome, PFPS, ACL sprains and other knee injuries and, ankle ligament injuries) were included in the subsequent analysis.

Statistical analysis

Injury incidence and burden are presented as the number of injuries/1000 hours and, the number of absence days/1000 hours respectively, each with 95% confidence intervals (CI) (2). Both dependent variables were compared between control and experimental seasons, according to the injury rate ratio (IRR = injury incidence of control season divided by the injury incidence of experimental season), with 95% CI and the Z test (26). Differences in player characteristics and exposure time were calculated using Student's t-test and compliance to the STIPP was calculated as a percentage of the total sessions available to each player and averaged for the total number of players. Significance was set at $p \leq 0.05$ and statistical analysis was performed using Microsoft Excel 2011 software (Microsoft, Redmond, WA, USA) and GraphPad Prism v.6.0c (GraphPad Software, La Jolla, CA, USA).

RESULTS

Participant characteristics and handball exposure

There were no significant differences between the control and the experimental seasons (Table 2) in anthropometric and demographic characteristics (i.e., age, height, body mass and body mass index) nor in the exposure time (i.e., total, training and match-play exposure). Compliance to the STIPP by players was 88.4%.

(Table 2 near here, please)

Injury incidence

There were no significant improvements in injury incidence for the total sessions, trainings or match-play from the control season to the experimental season (Table 3). A

192 significant lower injury rate was observed in lumbar injuries during the experimental
193 season (IRR = 55.83, 95% CI: 0.11–89.01; p = 0.001) compared with control season.
194 Nevertheless, no significant differences were found for injury by body site (i.e., ankle,
195 knee and thigh) or by type of injury (i.e., ligament sprain, muscular and tendon) between
196 the control and experimental seasons.
197
198 (Table 3 near here, please)
199
200 **Injury burden**
201 There were significant (IRR = 1.38-2.14; p = 0.001) improvements in injury burden
202 (number of absence days/1000 hours exposure) for the total sessions, trainings and match-
203 play from the control season to the experimental season (Table 4). There were significant
204 (IRR = 1.56-25.1; p = 0.001) improvements in injury burden for all the injury body sites
205 and types for the total sessions, trainings and match-play from the control season to the
206 experimental season.
207
208 (Table 4 near here, please)
209
210 **DISCUSSION**
211 The aim of this study was to analyze the effects of a STIPP on injuries associated with
212 gluteal muscles weakness in professional handball players. Although previous studies
213 have focused on injury prevention in team-sport athletes, this is the first investigation in
214 which a long-term strength training program focused on the gluteal muscles has been
215 applied in handball players. Compliance to the STIPP in our study was high (88.4%)
216 therefore the comparison between seasons for the players (15 players participated in both

seasons) was considered valid. The results of the study showed a non-significant reduction of injury incidence for total sessions, trainings and match-play, while a meaningful reduction of lumbar injuries was observed after the experimental season. In addition, the burden caused by injuries related to gluteal muscles weakness (i.e., lumbar injuries, hamstring injuries, ITB, PFPS, ACL and other knee injuries and, ankle ligament injuries) was also reduced after the inclusion of the STIPP.

Given that an injured player could have negative consequences for the sporting and economic interests of soccer clubs, strength-training programs could be the key because of their accessibility, effectiveness and cost-effectiveness for injury prevention in team-sport players (20,45). Regarding this, the strengthening of the gluteal muscles seems to be a critical aspect in injury prevention, correcting faulty movement patterns, eliminating pain, and enhancing athletic performance (23,25,31). Despite authors having suggested that injury-prevention programs could reduce injury incidence in team sport players (1,20,28), our study that used a STIPP with a gluteal muscles focus did not find any significant differences in the total number of injuries and the injury rate between the experimental season (21 injuries, 2.25 injuries/1000 hours) and the control season (30 injuries, 3.32 injuries/1000 hours). Both in training sessions (2.72 vs. 1.75, $p > 0.05$) and match-play (26.79 vs. 23.04, $p > 0.05$) the injury incidence was not significant between seasons. The greater injury incidence in match play was expected due to the greater stress imposed on players at the high competitive level both during match-play (7), mainly reflected by a greater amount of high-intensity actions (9).

Several pathologies have been related with gluteal muscles weakness (i.e., lumbar injuries, hamstring injuries, ITB syndrome, PFPS , ACL and other knee injuries and, ankle ligament injuries), affecting mainly the ankle, knee, thigh and lumbar body sites (37). Based on previous studies (14,15,25,43), a reduction of the injury incidence in the

aforementioned body sites could be expected after the application of the STIPP focused on the gluteal muscles. However, our study findings only partially support this theory, since only the number of lumbar injuries (7 vs 0; IRR = 55.83, 95% CI: 0.11–89.01; p = 0.001) were significantly reduced after professional handball players performed the STIPP. These results seem to be influenced by the fact that a general preventive program was applied (35) without a previous evaluation of each player's musculoskeletal performance. Individual player screening based on strength assessment of the gluteal muscles as well as a Q-angle lower limb evaluation may provide relevant information in order to optimize the effectiveness of the preventive programs (29). Despite this limitation, there was a significant reduction of the injuries of the lumbar area, a common pathology in handball players (33,34,38). Therefore, the STIPP could be an effective strategy to reduce lumbar injury incidence, since strong gluteal muscles allow handball players to hold the pelvis up and prevent it from moving laterally while walking, avoiding associated pathologies (37).

Analyses of the impact of injuries in terms of injury incidence only can provide a biased view. Each injury (count) does not have the same number of absence days (burden) from sport participation, so injury burden should be reported (2,30). This aspect becomes important given it has been reported that a strength training program with professional soccer players resulted in a significant reduction in injury severity but no significant difference in injury incidence (21). Our study results are in line with this previous study, given the application of the STIPP resulted in a reduction in the burden due to injuries during the experimental season compared with the control season attending to each exposure (i.e., total, training and match). In addition, the burden caused by injuries related to gluteal muscles weakness (i.e., lumbar injuries, hamstring injuries, ITB, PFPS, ACL and other knee injuries and, ankle ligament injuries) was reduced after the inclusion of

the STIPP. These findings support the idea that, despite the difficulty in reducing injury incidence in professional handball players, the application of preventive strength training stimuli during regular training may reduce training and match-play burden for injury sites (4,45).

The main limitation of this study was the application of a general injury-prevention strength training program, without attending to the specific demands of each handball player. Ideally a strength assessment of the gluteal muscles would have been conducted for each player to enable individualized strength-training programs. As players may respond differently to the STIPP based on their level of gluteal muscles function pre intervention strength testing should be a consideration for further detailed investigation. Finally, this preventive program has not been compared against another program, so results should be only applied to this sport population. Future studies should analyze the effects of individualized injury-prevention programs in both injury incidence and physical fitness.

CONCLUSION

The inclusion of an injury-prevention strength training program (STIPP) focused on gluteal muscles during regular training sessions in professional handball players only produced a meaningful reduction of lumbar injury incidence. However, the burden for injuries related to potential gluteal weakness (i.e., lumbar injuries, hamstring injuries, ITB, PFPS, ACL and other knee injuries and, ankle ligament injuries) was reduced during the experimental season.

PRACTICAL APPLICATIONS

Of practical relevance, current results indicate that the STIPP focused on gluteal muscles could be effective to reduce lumbar injuries and burden values in professional handball players. This finding may be of relevance for athletes, coaches and researchers, and the STIPP could be an interesting option, implemented in addition to the regular strength training, to reduce the injury risk of lumbar injuries in professional handball players.

REFERENCES

1. Askling, C, Karlsson, J, and Thorstensson, A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports* 13: 244–50, 2003.
2. Bahr, R, Clarsen, B, and Ekstrand, J. Why we should focus on the burden of injuries and illnesses, not just their incidence. *Br J Sports Med* bjsports-2017-098160, 2017.
3. Bere, T, Alonso, J-M, Wangensteen, A, Bakken, A, Eirale, C, Dijkstra, HP, et al. Injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar. *Br J Sports Med* 49: 1151–6, 2015.
4. Brockett, CL, Morgan, DL, and Proske, U. Predicting hamstring strain injury in elite athletes. *Med Sci Sports Exerc* 36: 379–87, 2004.
5. Cambridge, EDJ, Sidorkewicz, N, Ikeda, DM, and McGill, SM. Progressive hip rehabilitation: The effects of resistance band placement on gluteal activation during two common exercises. *Clin Biomech* 27: 719–724, 2012.
6. Cardinale, M, Whiteley, R, Hosny, AA, and Popovic, N. Activity profiles and positional differences of handball players during the World Championships in Qatar 2015. *Int J Sports Physiol Perform* 12: 908–915, 2017.
7. Castro-Sepulveda, M, Astudillo, J, Letelier, P, and Zbinden-Foncea, H. Prevalence

316 of dehydration before training sessions, friendly and official matches in elite
317 female soccer players. *J Hum Kinet* 50: 79–84, 2016.
318 8. Cronin, J, McNair, PJ, and Marshall, RN. Velocity specificity, combination
319 training and sport specific tasks. *J Sci Med Sport* 4: 168–78, 2001.
320 9. DiMascio, M and Bradley, PS. Evaluation of the most intense high-intensity
321 running period in English FA premier league soccer matches. *J Strength Cond Res*
322 27: 909–15, 2013.
323 10. Distefano, LJ, Blackburn, JT, Marshall, SW, and Padua, DA. Gluteal muscle
324 activation during common therapeutic exercises. *J Orthop Sport Phys Ther* 39:
325 532–540, 2009.
326 11. Earl, JE, Hertel, J, and Denegar, CR. Patterns of dynamic malalignment, muscle
327 activation, joint motion, and patellofemoral-pain syndrome. *J Sport Rehabil* 14:
328 216–233, 2005.
329 12. Ebben, WP. Complex training: a brief review. *J Sports Sci Med* 1: 42–6, 2002.
330 13. Ekstrand, J. Keeping your top players on the pitch: the key to football medicine at
331 a professional level. *Br J Sports Med* 47: 723–724, 2013.
332 14. Franettovich Smith, MM, Bonacci, J, Mendis, MD, Christie, C, Rotstein, A, and
333 Hides, JA. Gluteus medius activation during running is a risk factor for season
334 hamstring injuries in elite footballers. *J Sci Med Sport* 20: 159–163, 2017.
335 15. Fredericson, M, Cookingham, CL, Chaudhari, AM, Dowdell, BC, Oestreicher, N,
336 and Sahrmann, SA. Hip abductor weakness in distance runners with iliotibial band
337 syndrome. *Clin J Sport Med* 10: 169–75, 2000.
338 16. Friel, K, McLean, N, Myers, C, and Caceres, M. Ipsilateral hip abductor weakness
339 after inversion ankle sprain. *J Athl Train* 41: 74–8, 2006.
340 17. Hägglund, M, Waldén, M, Bahr, R, and Ekstrand, J. Methods for epidemiological

study of injuries to professional football players: developing the UEFA model. *Br J Sports Med* 39: 340–6, 2005.

18. Hamstra-Wright, KL and Huxel Bliven, K. Effective exercises for targeting the gluteus medius. *J Sport Rehabil* 21: 296–300, 2012.

19. Hase, K and Stein, RB. Turning Strategies During Human Walking. *J Neurophysiol* 81: 2914–2922, 1999.

20. van der Horst, N, Smits, DW, Petersen, J, Goedhart, EA, and Backx, FJG. The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: study protocol for a randomised controlled trial. *Inj Prev* 20: e8–e8, 2014.

21. De Hoyo, M, Pozzo, M, Sanudo, B, Carrasco, L, Gonzalo-Skok, O, Dominguez-Cobo, S, et al. Effects of a 10-week in-season eccentric overload training program on muscle injury prevention and performance in junior elite soccer players. *Int J Sport Physiol Perform* 10: 46–52, 2015.

22. Hughes, G and Watkins, J. A Risk-factor model for anterior cruciate ligament injury. *Sport Med* 36: 411–428, 2006.

23. Jeong, U-C, Sim, J-H, Kim, C-Y, Hwang-Bo, G, and Nam, C-W. The effects of gluteus muscle strengthening exercise and lumbar stabilization exercise on lumbar muscle strength and balance in chronic low back pain patients. *J Phys Ther Sci* 27: 3813–6, 2015.

24. Kang, S-Y, Jeon, H-S, Kwon, O, Cynn, H, and Choi, B. Activation of the gluteus maximus and hamstring muscles during prone hip extension with knee flexion in three hip abduction positions. *Man Ther* 18: 303–307, 2013.

25. Kim, E-K. The effect of gluteus medius strengthening on the knee joint function score and pain in meniscal surgery patients. *J Phys Ther Sci* 28: 2751–2753, 2016.

366 26. Kirkwood, B and Sterne, J. Essential Medical Statistics. 2nd edition. Blackwell
367 Science, 2003.
368 27. Kyröläinen, H, Avela, J, and Komi, P V. Changes in muscle activity with
369 increasing running speed. *J Sports Sci* 23: 1101–1109, 2005.
370 28. Lauersen, JB, Bertelsen, DM, and Andersen, LB. The effectiveness of exercise
371 interventions to prevent sports injuries: a systematic review and meta-analysis of
372 randomised controlled trials. *Br J Sports Med* 48: 871–877, 2014.
373 29. López-Valenciano, A, Ayala, F, Puerta, JM, de Ste Croix, M, Vera-García, FJ,
374 Hernández-Sánchez, S, et al. A preventive model for muscle injuries. *Med Sci*
375 *Sport Exerc* 50: 915–927, 2018.
376 30. Mallo, J, González, P, Veiga, S, and Navarro, E. Injury incidence in a spanish sub-
377 elite professional football team: a prospective study during four consecutive
378 seasons. *J Sports Sci Med* 10: 731–6, 2011.
379 31. Marshall, PWM, Patel, H, and Callaghan, JP. Gluteus medius strength, endurance,
380 and co-activation in the development of low back pain during prolonged standing.
381 *Hum Mov Sci* 30: 63–73, 2011.
382 32. van Mechelen, W, Hlobil, H, and Kemper, HC. Incidence, severity, aetiology and
383 prevention of sports injuries. A review of concepts. *Sports Med* 14: 82–99, 1992.
384 33. Mónaco, M, Rincón, JAG, Ronsano, BJM, Whiteley, R, Sanz-Lopez, F, and Rodas,
385 G. Injury incidence and injury patterns by category, player position, and maturation
386 in elite male handball elite players. *Biol Sport* 36: 67–74, 2019.
387 34. Olsen, O-E, Myklebust, G, Engebretsen, L, and Bahr, R. Injury pattern in youth
388 team handball: a comparison of two prospective registration methods. *Scand J Med*
389 *Sci Sports* 16: 426–32, 2006.
390 35. Owen, AL, Wong, DP, Dellal, A, Paul, DJ, Orhant, E, and Collie, S. Effect of an

391 Injury prevention program on muscle injuries in elite professional soccer. *J*
392 *Strength Cond Res* 27: 3275–3285, 2013.
393 36. Póvoas, SCA, Ascensão, AAMR, Magalhães, J, Seabra, AF, Krustrup, P, Soares,
394 JMC, et al. Physiological demands of elite team handball with special reference to
395 playing position. *J Strength Cond Res* 28: 430–442, 2014.
396 37. Presswood, L, Cronin, J, Keogh, JWL, and Whatman, C. Gluteus medius: applied
397 anatomy, dysfunction, assessment, and progressive strengthening. *Strength Cond*
398 *J* 30: 41–53, 2008.
399 38. Rafnsson, ET, Valdimarsson, Ö, Sveinsson, T, and Árnason, Á. Injury pattern in
400 icelandic elite male handball players. *Clin J Sport Med* 1, 2017.
401 39. Rozzi, SL, Lephart, SM, Gear, WS, and Fu, FH. Knee joint laxity and
402 neuromuscular characteristics of male and female soccer and basketball players.
403 *Am J Sports Med* 27: 312–319, 1999.
404 40. Schelling, X and Torres-Ronda, L. An integrative approach to strength and
405 neuromuscular power training for basketball. *Strength Cond J* 38: 72–80, 2016.
406 41. Schmitz, RJ, Riemann, BL, and Thompson, T. Gluteus medius activity during
407 isometric closed-chain hip rotation. *J Sport Rehabil* 11: 179–188, 2002.
408 42. Van Tiggelen, D, Wickes, S, Stevens, V, Roosen, P, and Witvrouw, E. Effective
409 prevention of sports injuries: a model integrating efficacy, efficiency, compliance
410 and risk-taking behaviour. *Br J Sports Med* 42: 648–52, 2008.
411 43. Tyler, TF, Nicholas, SJ, Mullaney, MJ, and McHugh, MP. The role of hip muscle
412 function in the treatment of patellofemoral pain syndrome. *Am J Sports Med* 34:
413 630–636, 2006.
414 44. Wedderkopp, N, Kaltoft, M, Holm, R, and Froberg, K. Comparison of two
415 intervention programmes in young female players in European handball--with and

without ankle disc. *Scand J Med Sci Sports* 13: 371–5, 2003

45. Zouita, S, Zouita, ABM, Kebsi, W, Dupont, G, Ben Abderrahman, A, Ben Salah, FZ, et al. Strength Training reduces injury rate in elite young soccer players during one season. *J Strength Cond Res* 30: 1295–1307, 2016.

Figure and table legends

Figure 1. Schematic representation of the study design.

Figure 2. The three strength-training exercise types which involved active mobilization, strengthening and proprioception, and their progression steps.

Table 1. The strength training injury-prevention program (STIPP) progression.

Table 2. Anthropometric and demographic measures, and exposure time (mean ± standard deviation) of the participants in the control (21 players) and experimental (20 players) seasons.

Table 3. Injury incidence (injuries/1000 hours exposure) during the control (21 players) and experimental (20 players) seasons.

Table 4. Injury burden (number of absence days/1000 hours exposure) according to body site and type for total, trainings and matches during the control (21 players) and experimental (20 players) seasons.