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Stretching and Injury Prevention in Football: Current Perspectives

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Stretching exercises are regularly recommended as a part of football-training sessions and in preparation for competition. There is little sound empirical evidence, however, to substantiate the role of stretching exercises and consequently increased flexibility on injury prevention in football. Furthermore, in the last decade or so, fundamental research has shed some light on the biomechanical adaptation of the muscle-tendon unit following different stretching protocols, improving knowledge about the topic and enabling better understanding of the stretching-injury relationship. The purpose of this review is to examine the literature on the role of stretching and/or increased flexibility on injury prevention in football, with presented results analyzed in the context of the up-to-date basic science research evidence.

KEYWORDS *injury rate, flexibility, hamstrings, muscle-tendon unit*

INTRODUCTION

Association football (soccer) is the most popular sport, with over 200 million professional players worldwide (Dvorak, Junge, & Graf-Baumann, 2004). Match activity pattern is characterized by repeated bouts of high intensity exercise interspersed with periods of lower intensity or passive recovery (Bangsbo, Mohr, & Krustrup, 2006) inducing considerable cardiovascular

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stress (Yu, Katoh, Makino, Mimuno, & Sato, 2010). In addition, game activities consist of important performance elements such as duels, jumps, and kicks requiring maximal strength and anaerobic power of the neuromuscular system (Hoff & Helgerud, 2004; Reilly, 2005; Wisløff, Helgerud, & Hoff, 1998). To become successful in this type of activity, beyond well-developed technical and tactical skills, football players need a high level of physical preparedness. It has been shown that a strong relationship exists between physical fitness and performance level in elite football (Ostojic, 2004). Moreover, it appears that physical fitness has become more and more important in helping football players cope with the sport's increasing physiological demands (Orhant, Carling, & Cox, 2010; Williams, Lee, & Reilly, 1999). This prerequisite implies the need for exposure to strenuous training regimens on a daily basis, inducing high weekly training load with substantially taxed metabolic, musculoskeletal, and nervous and immune systems during a season (Babwah, 2011; Bangsbo et al., 2006; Filaire, Bernain, Sagnol, & Lac, 2001; Rebelo et al., 1998). Such a strenuous training schedule will, it is hoped, result in optimal levels of physical fitness (Brink, Nederhof, Visscher, Schmikli, & Lemmink, 2010a), but it may also increase likelihood of injuries as it has been shown that weekly training load is one of the strongest injury occurence predictors (Brink et al., 2010b).

The incidence of football injury has been extensively investigated with heterogeneous results presented (Babwah, 2009; Dvorak & Junge, 2000; Ostojic, 2003; Yard & Comstock, 2009). On average, an elite male football player suffers approximately one performance-limiting injury each year, with overall incidence estimated to be approximately 10 to 15 injuries per 1,000 playing hours (Chomiak, Junge, & Peterson, 2000), of which 88% affect the lower extremities (Heidt, Sweeterman, & Carlonas, 2000). Thus, the injury risk is considerable and higher as compared with that of most other team sports (Junge, Dvorak, Graf-Baumann, & Peterson, 2004). Injuries imply periods of training cessation or a marked reduction in the training load, resulting in a loss of previously acquired physiological and performance adaptations. Moreover, a period of suboptimal physical fitness can be expected for considerable time after injury (Mujika & Padilla, 2000), which further prolongs the period of individual and team underperformance. Finally, in the study of Arnason and coworkers (2004) a trend between a high number of days lost to injury and lack of team success has been established. Hence, there is every reason to emphasize the prevention of injuries in football, with inclusion of different training protocols targeting intrinsic injury risk factors (Junge & Dvorak, 2004).

Although the incidences of injury in football have been described in detail (Dvorak & Junge, 2000; Le Gall, Carling, Reilly, Vandewalle, Church, & Rochcongar, 2006), much less is known about specific risk factors. A lack of muscle flexibility traditionally has been considered an important risk factor for the development of football injuries. In addition, it has been documented that stretching exercises increase the maximal joint range of motion (Halbertsma & Goeken, 1994; Magnusson, Simonsen, Aagaard, Sorenson, & Kjaer, 1996b; Wilson, Elliot, & Wood, 1992). Consequently, stretching exercises are regularly recommended as part of football-training sessions and in preparation for competition. However, there currently appears to be little sound empirical evidence to substantiate the role of stretching exercises and increased flexibility on injury prevention in football, with literature on the subject being scarce and contradictory. Furthermore, in the last decade, fundamental research has shed some light on the biomechanical adaptation of the muscle-tendon unit following different stretching protocols, enabling somewhat better understanding of the stretching-injury relationship. Hence the purpose of this review is to examine the literature on the role of stretching and/or increased flexibility on injury prevention in football, with presented results analyzed in the context of current basic science research.

STRETCHING-INDUCED MUSCLE-TENDON UNIT ADAPTATION

The underlying mechanisms that can reduce injury as a consequence of stretching are not apparent or easily understood. Kirkendall and Garrett (2002) state that increased visco-elastic properties of a muscle can decrease the strain in a muscle. To enhance understanding of possible mechanisms through which stretching may reduce musculo-tendinous injury incidence, we will review basic science research examining muscle-tendon unit responses to different stretching protocols.

The main purpose of stretching is to increase muscle-tendon unit length, which is done by muscle visco-elastic property alterations. Viscosity refers to the elongation of a tissue that remains once the force applied to it is removed, while elasticity refers to the return of the tissue to its original length when the force is removed (Mujika & Padilla, 2000). The visco-elastic properties of muscle result in several phenomena when an external load is applied: stress relaxation, creep, and hysteresis. Past research failed to demonstrate a relationship between these phenomena and the rate of muscle injury (Magnusson, 1998; Magnusson et al., 1996b; Taylor, Dalton, Seaber, & Garrett, 1990; Weerapong, Hume, & Kolt, 2004). However, the ratio of the change in resistance to the change in length, termed *stiffness* (or *compliance* as a converse term; Halbertsma & Goeken, 1994) is thought to be more relevant, as a less stiff muscle can extend to a greater length, allowing greater absorption of energy in response to applied forces (Magnusson, Aagaard, Simonsen, & Bojsenmoller, 1998; McNair & Stanley, 1996), and therefore could be less susceptible to strain injury. Can stretching improve compliance of the muscle-tendon unit?

Acute effects of stretching on muscle-tendon visco-elastic properties have been extensively studied, and they have clearly shown that after several stretch episodes a decrease in muscle stiffness (or an increase in muscle compliance) occurred (Table 1).

Kubo and coworkers (2001, 2002) reported that 5 and 10 min of stretching decreased tendon stiffness. Although this is an important finding, its relevance to common sport practice is unclear, primarily due to the extremely long holding time compared with those routinely used in typical stretching regimens (30–60 s hold). Magnusson and coworkers (1995, 1996a) showed that stretching for five times during 90 s reduced muscle stiffness and stress relaxation, with the decline in stiffness returning to baseline within 1 hour. Other authors reported that using 60 s stretch holding times also has the potential to reduce muscle-tendon stiffness (McNair, Dombroski, Hewson, & Stanley, 2000; Morse, Degens, Seynnes, Maganaris, & Jones, 2008). However, treatment programs that consisted of 3–10 sets of 15- to 30-s static stretching for hamstrings followed by a 20- to 30-s period of relaxation did not induce a significant change in the joint angle-passive torque relation (stiffness) after the stretching (Halbertsma, van Bolhuis, Goeken, 1996; Wiemann & Hahn, 1997). Moreover, according to Magnusson and coworkers (1995, 1996a), no significant decline in passive resistance was found after 40–45 s of the 90-s stretch for hamstrings. Altogether, these findings suggest that acute changes of visco-elastic muscle-tendon properties are highly dependent on the duration of the stretch, with over 45 s appearing to be required if decreased stiffness is the goal. It has been suggested that an immediate adaptation of both parallel and serial elastic component to imposed load could be responsible for the observed decline in the stiffness of muscle-tendon units after stretching (Magnusson et al., 1996b). In addition, the observed adaptation of parallel and serial elastic component might be attributed to an acute change in the arrangement of collagen fibers (Stromberg & Wiederhielm, 1969). The literature is scarce and equivocal considering chronic effects of stretching on visco-elastic properties. Magnusson and coworkers (1996b) reported that long-term training using 10 stretches for 45 s per day during 3 weeks did not change visco-elastic properties of muscle, with similar results presented by Klinge and coworkers (1997) with four 45 s stretches, two sessions per day, 7 days per week for 13 weeks stretching regimen. However, Mahieu and coworkers (2007) showed significant decrease in passive stiffness after 6 weeks of a stretching program that consisted of five 20-s stretches with 20 s of rest. Although further studies are needed to confirm this finding, it is suggested that visco-elastic properties of muscle-tendon unit could be chronically altered by regular stretching.

It should be noted that muscle-tendon unit stiffness is dependent on two different components: muscle stiffness and tendon stiffness. In an authoritative review (Witvrouw, Mahieu, Danneels, & McNair, 2004), the authors suggested that tendon stiffness could be responsible for the association

TABLE 1 The Effects of Stretching on Biomechanical Muscle-Tendon Properties: Basic Science Studies

Reference	Study design	Participants	Muscle group	Intervention	Outcomes
Magnusson et al. (1995)	PPT	10 men	Hamstrings	Static stretch (hold 90 s, rest 30 s) 5 times	Decreased stiffness; increased ROM
Halbertsma et al. (1996)	RCT	Exp. group (n = 10) Control group (n = 6)	Hamstrings	Static stretching (30 s hold × 30 s rest) for 10 min	Increased ROM; no change in stiffness
Magnusson et al. (1996a)	PPT	13 healthy subjects	Hamstrings	Static stretch (hold 90 s, rest 30 s) 5 times	Decreased stiffness
Magnusson et al. (1996b)	PPT	7 women	Hamstrings	Static stretch (45-s hold × 15–30 s rest × 5 times) twice a day for 20 days	Increased ROM; no change in stiffness
Klinge et al. (1997)	CCT	Exp. group (n=12) Control group (n=10)	Hamstrings	4 × 45 s static stretch twice a day, 7d/w for 13 weeks	No change in stiffness
Wiemann et al. (1997)	CCT	Static stretc. group (n=14) Ballistic stretc. group (n=16) Control group (n=15)	Hamstrings	For both groups: 3 sets of 3 × 15 s, 20 s of rest between repetitions, 3 min between sets	Increased range of motion; no change in stiffness
Magnusson et al. (1998)	CCT	12 men	Hamstrings	(i) 90-s static stretches; (ii) continuous movements 10 times at 20°/s	Increased ROM
McNair et al. (2000)	CBT	15 men and 8 women	Plantar flexors	Static stretching. (1) 1 × 60 s; (2) 2 × 30 s; (3) 4 × 15 s; cont. passive movement – 60 s	Continuous movement - decreased passive stiffness. Hold condition - decreased peak tension
Kubo et al. (2001)	CBT	7 men	Plantar flexors	Passive stretching for 10 min	Decreased tendon stiffness (10%)
Kubo et al. (2002)	CBT	8 men	Plantar flexors	Passive stretching for 5 min	Decreased tendon stiffness (8%)

(*Continued*)

TABLE 1 (Continued)

Reference	Study design	Participants	Muscle group	Intervention	Outcomes
Mahieu et al. (2007)	RCT	Static stretc. group ($n = 31$) Ballistic stretc. group ($n = 21$) Control group ($n = 29$)	Plantar flexors	For both groups: 5 × 20 s stretch with 20 s rest; 7 d/w for 6 weeks	Static stretching group: increased ROM, decreased muscle stiffness Ballistic stretching group: increased ROM: decreased Achilles tendon stiffness
Morse et al. (2008)	PPT	8 healthy men	Plantar flexors	Static stretching: 5 × 1min	Reduced passive stiffness by 47%
Mahieu et al. (2009)	RCT	PNF stretc. group ($n = 33$) Control group ($n = 29$)	Plantar flexors	6 weeks of 5 × (15 s-6 s-15 s) with 20 srest for static stretching, isometric and antagonistic contraction, respectively.	Increased ROM No change in muscle or tendon stiffness

Note. CCT: controlled clinical trial; RCT: randomized controlled trial; PPT: pre- and post-test trial; CBT: counterbalance trial.

between reduced flexibility and occurrence of muscle injury during short-burst activities involving stretch-shortening cycle (SSC—an active stretch/eccentric contraction of the muscle followed by an immediate shortening of that same muscle). Specifically, the stiffer the tendon, the greater the force that will be transferred to the muscle during fast eccentric contraction, with augmented muscle-injury risk. In this context, it should be noted that football players have been shown to be less flexible than a control group (Ekstrand & Gillquist, 1982), with an inverse relationship found between flexibility and player skill level (Ostojic & Stojanovic, 2007). Therefore, improving tendon compliance (reducing stiffness) with frequent SSC-type activity could be important for muscle strain prevention in all sports. In the series of studies Kubo and coworkers (2001, 2002) reported both acute and chronic decreases in tendon stiffness as a result of a stretching training regimen. The recent study by Mahieu and coworkers (2007) provides further support. In the randomized control trial study design, the authors showed that after 6 weeks of training (five 20-s stretches with 20 s of rest for 7 days a week) both static and ballistic stretching improved range of motion. In addition, static stretching resulted in a significant decrease in passive resistive torque, with no change in tendon stiffness. In contrast, ballistic stretching had no significant effect on passive resistive torque but has been found to significantly decrease tendon stiffness. Hence, ballistic stretching done on a daily basis and in the volume that is regularly done in everyday football training could resolve in a more compliant tendon. It has been reported that this type of stretching improves range of motion (Shellock & Prentice, 1985) with pre-exercise inclusion with negligible negative effects on strength (Bacurau et al., 2009) and may increase power (Woolstenhulme, Griffiths, Woolstenhulme, & Parcell, 2006). Finally, it increases core temperature (Fletcher, 2010). Hence, ballistic stretching might be an effective training tool that simultaneuosly prevents injuries, provides a warm-up, and augments performance. However, further studies are warranted to clarify this assumption.

Summarizing presented data in the context of football, several conclusions can be made. First, acute stretching effects on muscle-tendon stiffness showed that, as far as injury prevention is concerned, commonly observed pre-exercise-stretching practices are unlikely to be effective. In order to obtain altered muscle-tendon stiffness, four to five sets of 60–90 s of static stretching or ballistic stretching seems needed. Second, since the long term stretching effect on tendon visco-elastic property is still subject to debate, no clear recommendation can be made considering the optimal duration and frequency of regular stretching practices. Third, it seems that different types of stretching have different effects on the muscle-tendon tissue properties, with only long-term ballistic stretching found to decrease tendon stiffness significantly (Mahieu et al., 2007; Mahieu, Cools, Wilde, Boon, & Witvrouw, 2009), possibly leading to fewer injuries in short-burst type activities.

THE ROLE OF STRETCHING AND FLEXIBILITY IN REDUCING INJURY RISK IN FOOTBALL

There is a paucity of data regarding stretching and flexibility on injury risk in football players (Table 2).

In one paper, authors used stretching exercises as one of several simultaneously used preventive programs (Ekstrand, Gillquist, & Liljedahl, 1983), while others investigated the relationship between flexibility and specific muscle injuries (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008; Dadebo, White, & George, 2004), or determined the influence of preseason flexibility on the risk of muscle strain injury during a season (Bradley & Portas, 2007; Henderson, Barnes, & Portas, 2010; Witvrouw, Danneels, Asselman, D'Have, & Cambier, 2003). One of the most cited articles is pioneering work of Ekstrand et al. (1983) in which the effectiveness of a multi-factorial program to reduce injury incidence in male senior football players was evaluated. The 15 most skilled players from 12 teams were randomly assigned to either an intervention ($n = 90$; 6 teams) or control group ($n = 90$; 6 teams), with the intervention group adhering to a seven-part preventive program, including 10 min of stretching exercises. During a 6-month follow up, about 75% fewer injuries were obtained in the intervention group as compared with the control group (0.6 injuries per month *vs.* 2.6 injuries per month, respectively, $p = 0.001$). The second phase of the study consisted of the same intervention provided by coaches only, with results showing a somewhat smaller reduction in injury rate (50%). Overall, this study showed the effectiveness of a multi-component program including stretching exercises. However, considering that the prevention program was multifaceted and addressed many factors that could be related to the risk of injury (e.g., the correction of training with additional 10 min stretching; provision of shin guards and special shoes during winter training; prophylactic ankle taping in players with clinical instability or history of previous sprain; controlled rehabilitation; exclusion of players with serious knee instability; information about the importance of disciplined play and the increased risk of injury at training camps; and correction and supervision of doctors and physiotherapists), it is not possible to determine exactly the contribution of stretching exercises for the observed effects.

Dadebo et al. (2004) investigated the relationship between current stretching training protocols and hamstring strain rates in football players. Flexibility training methods data and hamstring strain rates were collected from English professional football clubs ($n = 30$; division 1–4) via questionnaire. Authors reported that a substantial amount of total training time was devoted to flexibility training, with about 40% being an average amount across divisions. In addition, static stretching was reported as the most popular stretching technique used among most clubs, with many combining it

TABLE 2 Flexibility/Stretching and Injury Prevention: Football Related Studies

Reference	Study design	Participants	Intervention	Outcomes
Ekstrand et al. (1983)	Randomized control trial	Intervention group = 90 Control group = 90	Seven part preventive program (10 min stretching included)	Fewer injuries in the intervention than in the control group (0.6 vs. 2.6 injuries per month, $p = 0.001$)
Witvrouw et al. (2003)	Prospective	146 players	None	Significantly lower flexibility of hamstringand quadriceps muscles in injured than uninjured group
Dadebo et al. (2004)	Observational	30 teams	None	Static and PNf stretching found to be significantly associated with lower hamstring strain rate ($r = 20.53$, $p = 0.01$)
Bradley and Portas (2007)	Prospective	36 players	None	Significantly lower preseason range of motion for injured than uninjured players
Arnason et al. (2008)	Intervention	17–30 teams during 4 seasons	3 × 55 s hamstring stretch (PNF), one/two (season) and three times a week (preseason)	No difference in the incidence of hamstring strains between groups
Henderson et al. (2010)	Prospective	36 players	None	Range of motion demonstrated a trend for being higher in non-injured than injured players. Active ROM significantly contribute to regression model predicting propensity for hamstring injury

with proprioceptive neuromuscular facilitation (PNF) stretching (combination of passive stretching and isometric contraction during single repetition in order to achieve maximum range of motion). The longest duration of stretching exercise, about 30 s, was observed in Premiership teams, whereas players in other divisions stretched for 20 s or less. Interestingly, a static stretching protocol seems to be the only training factor that correlated significantly with hamstring strain rate ($r = -0.53$, $p = 0.01$). In addition, stepwise multiple regression analysis indicated that stretching was the most important factor associated with hamstring strain rate, with stretching holding time being the single most important predictor, accounting for nearly 30% of variability. The authors suggest that the stretching protocols currently used by professional footballers may have potential for prevention of hamstring strains, but one must consider appropriate stretching holding time employment.

The purpose of another study, conducted by Witvrouw et al. (2003), was to examine whether a relative lack of muscle flexibility before the season could identify a professional football player at risk for a musculoskeletal injury of the lower extremity. Flexibility of the hamstring, quadriceps, adductor, and gastrocnemius muscles was measured with a goniometer before the start of the season on 146 male professional football players. Team physicians documented all muscle injuries of the lower extremities, the amount of time spent in training, and the amount of time played in games for each player during the season. Results revealed that 67 players sustained a clinically diagnosed muscle injury of the lower extremity. No differences were found in the amount of time spent in training and games between the injured and uninjured players, implying that the injury incidence could be primarily intrinsic risk factor-dependent. Statistical analysis found a difference between the injured and the uninjured players in both quadriceps and hamstring muscle flexibility, with the injured group showing a significantly lower flexibility. Furthermore, stepwise logistic regression identified the flexibility of the hamstring and quadriceps muscles as an intrinsic risk factor for musculoskeletal muscle injury. The authors stated that a significant correlation was found between players with decreased flexibility of the hamstring muscles (less than 90°) and the occurrence of a hamstring muscle injury. Also, they suggest that stretching should be viewed as an important part of a prevention program for muscle injuries in football.

In contrast to the previously reported study are the results of Arnason and coworkers (2008). They conducted an intervention study during four consecutive football seasons for 17–30 elite football teams from Iceland and Norway, with the purpose of testing the effects of eccentric strength and flexibility training on the risk of hamstring strain. After 2 years used as baseline, a preventive program (which consisted of three exercise components: warm-up stretching, flexibility training, and/or eccentric strength training) was introduced to the clubs, and 48% of the teams were appointed to the intervention programs. Interestingly, the flexibility training program consisted of only one exercise, hamstring stretch, with three 55 s repetitions for each leg, which far exceeds length of stretch-repetition regularly performed in professional football clubs (Dadebo et al., 2004). This exercise was done after training three times per week during the preseason period and one to two times during the competitive season. All noncontact-induced hamstring strains were recorded during the competitive season on the monthly basis. Results of the study revealed no effect of stretching during warm-up and hamstring-flexibility training on the incidence of hamstring strains, in contrast to eccentric strength training, which in combination with warm-up stretching seems to be effective. In conclusion, authors stated that flexibility training alone is unlikely to prevent hamstring strains in football players.

The effect of preseason lower extremity range of motion on muscle strain injury during the competitive season was examined in the prospective study by Bradley and Portas (2007). Thirty-six elite male football players were assessed prior to the season. Maximum static range of motion for 6 movements of the lower extremity was measured for the dominant and non-dominant kicking leg of each player. Obtained results revealed a significant difference ($p < 0.05$) in the range of motion of the hip and knee flexors between the injured and uninjured players. A multivariate analysis (range of motion, age, body size, limb dominance, and playing position were included) identified a low range of motion of the knee flexors ($p < 0.01$) and hip flexors ($p < 0.05$) as a significant contributing factors for a subsequent muscle strain injury. Other range of motion indicators, body size, age, and playing position were non-significant contributing factors. Players who injured the knee or hip flexor muscles during the season had a preseason range of motion approximately 3° less than that of the uninjured players. Possible explanation for low range of motion in the hip and knee flexors producing a higher injury rate may be that these muscles frequently are used at maximal range of motion during high speed movements, such as sprinting (Williams, 2000) as required in a football game (Chomiak et al., 2000). Players with a greater range of movement may have a "flexibility reserve" with respect to such activities, which reduces muscular tension and thus helps them to avoid injury.

Recently, Henderson et al. (2010) examined the influence of a number of physical and performance parameters on subsequent incidence of hamstring injury in English Premier League football players. Thirty-six healthy, elite, professional football players were assessed during the first week of preseason training for anthropometry, flexibility, lower limb strength and power, speed, and agility. Active and passive hip flexion range of motion for both the dominant and non-dominant leg of each player were used as indicators of flexibility. During the 45 weeks of the competitive season, all injuries requiring medical attention were recorded. Using forward stepwise logistic regression to assess the impact of several factors collectively on the likelihood of hamstring injury occurence, four independent variables (age, active range of motion, explosive power, and lean mass) were found to have a strong combined influence. In addition, the data showed that for every degree of decreasement in active straight leg raise, propensity for injury increased × 1.29 (1/0.77). The authors suggested that the structure of training programs for football players should account for their suceptibility to hamstring injury and be structured around appropriate preventive protocols. Consequently, as a lower injury risk through improvements in active range of motion has been established, the authors propose that stretching should be an integral part of such protocols.

Summarizing the aforementioned studies, it can be postulated that research conducted on football players supports an association between stretching and/or increased flexibility and injury incidence reduction, with only one study finding no relationship (Arnason et al., 2008). This is unexpected, as several systematic reviews (Table 3) showed no preventive effects of stretching and warm-up programs on the rate of injuries in non-football players (Hart, 2005; Herbert & Gabriel, 2002; McHugh & Cosgrave, 2010; Thacker, Gilchrist, Stroup, & Kimsey, 2004).

However, studies in those reviews evaluated the relationship between stretching and overall injury rates, while some injuries may be unavoidable and stretching nondependent. Amako, Oda, Masuoka, Yokoi, & Campisi (2003) showed that, although no difference was observed in the rate of total injuries between the control and intervention groups, occurrence of muscle-tendon-related injuries was significantly lower in the stretching group of military recruits. A review by Small, McNaughton, and Matthews (2008) presented evidence supporting static stretching-potential in reducing the incidence of musculotendinous and ligament sprain type injuries, but not overall injury rates. A recent review (McHugh & Cosgrave, 2010) also suggests that stretching may be beneficial for reducing muscle strains, with four out of seven cited studies showing some stretching effect. In addition, it has been noticed that all four studies were conducted in high prevalence muscle strain sports, indicating that beneficial stretching effects could be muscle strain prevalence-dependent. Finally, admitting there is difficulty in isolating the effect of stretching alone, the authors stated that larger controlled trials are needed in order to substantiate these findings.

Several limitations hinder the presented results. First, most did not investigate the effects of a stretching protocol on injury occurrence, but rather the different injury rates in football players with different range of motion. However, different range of motion may not be related to the effect of stretching, but rather to the underlying inter-individual variations in tissue properties (Shrier, 2007). Second, except for the study done by Ekstrand et al. (1983), none of the research complies with randomized control trial study design (RTC), which is considered the gold standard for assessing the effectiveness of a treatment (Byar et al., 1976). Although Shrier (2000) stated

TABLE 3 Flexibility/Stretching and Injury Prevention: Systematic Review Articles

Reference	Methodology	No. of studies included	Participants	Outcomes
Herbert and Gabriel (2002)	Meta-analysis	2	Military recruits	Muscle stretching before exercising does not produce meaningful reductions in the risk of injury.
Thacker et al. (2004)	Meta-analysis	6	Military recruits, navy midshipmen, American football players	Stretching was not significantly associated with a reduction in total injuries
Small et al. (2008)	Meta-analysis	7	College american football players, military recruits, recreational runners	Stretching have no effect in reducing exercise-related injury. Stretching may reduce musculotendinous injuries
McHugh and Cosgrave (2010)	Review	7	Yachting crew, recreational runners military recruits, American football players	Stretching in addition to warm-up does not affect the incidence of overuse injuries, but may be beneficial for reducing muscle strain

that the use of non-RTC studies may weaken conclusions, results obtained using this design should be interpreted with caution (Hopkins, 2000).

Third, apart from general deficiencies in study design, each study has unique limitations. As previously mentioned, the study by Ekstrand and coworkers (1983) included multiple interventions, which makes it difficult or impossible to attribute the reduced injury risk to stretching alone. In addition, similar constraints are found in the study conducted by Henderson and coworkers (2010). Dadebo and coworkers (2004) failed to provide larger sample size, with training protocols obtained for teams as a whole, not individual players—raising concerns about individual adherence to group program. In another study (Witvrouw et al. 2003), of all proposed intrinsic risk factors presented in the literature, such as previous injury, strength, strength imbalance, and proprioception (Arnason et al., 2004; Caraffa, Cerulli, Projetti, Aisa, & Rizzo, 1996), the authors examined only muscle flexibility. In the study of Bradley and Portas (2007), 32 out of 36 subjects who sustained muscle strain injury were allocated to the injury group and compared with only four subjects in the uninjured group, raising the question of adequate sample (Vincent, 2005). Finally, Arnason and coworkers (2008) reported that they could not control how well the intervention program was performed with relatively low compliance to the program (48%). Fourth, all presented studies used range of motion as a measure of flexibility, probably referring to its most prevalent definition and worldwide accepted practice for decades (Alter, 1996; Magnusson & Renstrom, 2006). It has been shown, however, that stretching-induced alterations in range of motion may be primarily related to increased pain tolerance (Halbertsma et al., 1996), and not altered biomechanical muscle properties (Magnusson, 1998). The mechanism responsible for the observed effects is unclear however, as there was a lack of association between increased range of motion and stretching-induced alterations in musculo-tendinous properties.

CONCLUSION AND FUTURE DIRECTIONS

Based on available research data, it is likely that increased flexibility results in decreased incidence of muscle strain injury in football players. Hence, stretching as an intervention may have a positive effect on preventing musculo-tendinous injuries. However, this assumption should be accepted with caution, as it is grounded on rather indirect evidence. We found a deficiency of research that identifies the role of stretching in injury prevention in football players. At this point, it is not clear which stretching practices are effective for injury prevention. Consequently, no scientifically based prescription for stretching exercises exists and no conclusive statements can be made about the relationship of stretching and football injuries. Stretching recommendations in common practice are clouded by misconceptions and are mostly based on unsystematic observations. Many of the proposed stretching methods and their relationship with specific types of injury in football demand further studies using stronger methodological quality. Finally, investigators should take into account the insights obtained from the basic and possibly experimental science literature in order to improve study methods and outcome measure selection.

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