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**A SYSTEMS-BASED APPROACH TO INJURY PREVENTION FOR THE  
STRENGTH AND CONDITIONING COACH**

1   **ABSTRACT**

2   Participation in sport exposes athletes to an inherent risk of injury. In order to  
3   develop a comprehensive injury prevention program, strength and conditioning  
4   coaches must conduct a thorough needs analysis to establish the risk of injury,  
5   identify mechanisms and risk factors for injury, select relevant screening tests  
6   and design targeted interventions based on the athlete's results. Using a  
7   systems-based approach presented herein, this article provides an overview of  
8   the process that coaches must undertake in order to develop effective injury  
9   prevention programs.

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## 1 INTRODUCTION

2 With sports participation, there is an inherent risk of injury that is unavoidable  
3 (26); however, reducing the incidence of injuries is one of many priorities for  
4 strength and conditioning (S&C) coaches alongside the development of  
5 relevant physical qualities. In order to design an S&C program that enhances  
6 performance whilst reducing injury risk, a thorough needs analysis should be  
7 conducted for each athlete that is both relevant to the sport and the individual  
8 (70).

9  
10 Generic movement screening systems have previously been suggested as a  
11 useful tool for identifying injury risk (43, 68) and have been employed by high  
12 level professional organizations for the purpose of identifying athletes at risk of  
13 injury (52). However, these methods demonstrate little capacity to identify injury  
14 risk within large-scale studies with substantial sample sizes (5, 53, 57). This  
15 may be due to deviations from their original design, which was to establish  
16 foundational movement competency in non-specific activities (14), along with  
17 many prospective cohort studies using sample sizes that are too small to  
18 accurately identify risk factors (49). An approach focused on examining the  
19 relevant movement patterns which are reflective of the demands of the sport  
20 and mechanisms of injury, is likely to be required to prevent sports injuries (8).  
21 More recently, the ability to predict injury has been questioned due to the multi-  
22 factorial nature and unique circumstances that accompany an injury incident  
23 (9). Nonetheless, the current body of evidence indicates that the application of  
24 well-designed interventions, encompassing resistance training, plyometrics,

1 balance and skill training does reduce modifiable risk factors (39, 41, 59, 60),  
2 and the subsequent reduction of injury risk (8).

3

4 The objective of this article is to provide S&C coaches with a systems-based  
5 approach to reduce injury risk with their athletes, along with presenting an  
6 example of how this model could be applied to enhance practical application.  
7 This includes clear sequencing, whereby evidence-based screening tools are  
8 used and the information gathered from this process will then allow coaches to  
9 design injury prevention programs to target modifiable risk factors. This model  
10 is based on the work of van Mechelen et al. (79) and Finch (25). Modifications  
11 have been made for application in the setting of a S&C program. This approach,  
12 which along with effective monitoring of the training program to manage the  
13 distribution of load, has a greater potential to reduce an athlete's injury risk.

14

## 15 **CONSIDERATIONS FOR DEVELOPING AN INJURY PREVENTION MODEL**

16 Prior to the implementation of any training intervention, the S&C coach must  
17 understand the demands of the sport and the athlete's ability to cope with those  
18 requirements. Similar to the design of a performance program, a needs analysis  
19 relevant to injury risk must be conducted (70). Using this information, a testing  
20 battery can be designed and implemented in order to identify and reduce  
21 modifiable baseline risk factors. Figure 1 illustrates this five-step process for  
22 the injury prevention model. After discussing the five step process, a relevant  
23 demonstration of how this process can be employed through a case study.

24

25 \*INSERT FIGURE 1 HERE\*

1

2 By applying this systems-based approach to designing and implementing an  
3 injury prevention program, S&C coaches will be able to plan effective strategies  
4 to reduce injury risk. In addition to accurate documentation of the occurrence  
5 of athlete injuries, this approach will allow for the continual development of an  
6 injury prevention program that can be refined and updated as new evidence  
7 becomes available within both the literature and the coaches practice. It is  
8 important to note that this approach must align with the development of the  
9 athlete's physical and sports performance, and should rarely be seen as a  
10 separate component. From this perspective, the injury prevention program is  
11 viewed as an inclusive element to the training process that allows the athlete to  
12 thrive in their sporting environment.

13

## 14 **STEP 1: ESTABLISH THE RISK OF INJURY THROUGH SPORTS** 15 **PARTICIPATION**

16 The first step in identifying the injury risk associated with a sport is to examine  
17 the injury epidemiology in the literature (25). This allows coaches to establish  
18 the injury incidence for any given sport, which represents the number of injuries  
19 occurring relative to the time participating in either training or competition for  
20 the sport, divided by the number of athletes included in the data collection  
21 process (79). The major issue with this type of analysis is the manner in which  
22 injuries are reported (24). Finch (25) suggests the following methodological  
23 limitations exist within injury surveillance research:

24

- 25 1. The use of many injury survey's that have not been validated.

- 1        2. Recall bias present with retrospective data collection as athlete's report
- 2        injuries a long time following the onset of the injury.
- 3        3. Studies fail to define sports injury as well as severity.
- 4        4. Failing to report exposure to sport via training or competition as it relates
- 5        to injury incidence.

6

7    Although recent literature has accounted for many of these issues, coaches  
8    must be sure to critically analyze the research that they use to inform their  
9    model. Importantly, research used to inform the training process should include  
10   validated measures for data collection, use of a prospective study design,  
11   documentation of the severity of injuries by identifying days missed from sport  
12   participation, and establish the athlete's exposure to training and competition.  
13   For further details and observation of consensus statements for the undertaking  
14   and examination of injury surveillance research, coaches should review the  
15   following resources (28, 29, 42).

16

17   Alongside such considerations, coaches should also be sure to incorporate  
18   research that is specific to the sport and their athletes profile in order for the  
19   incidence data to be valid. For example, injury epidemiology research should  
20   be evaluated based on the sex (36), age (74), player position (76), level of  
21   competition (33, 34), and the era in which the data were recorded due to  
22   potential rule changes or changes in sport demands (15, 35). Thus, research  
23   used to inform the injury prevention model must be relevant to the athlete and  
24   their sport for successful outcomes to be achieved.

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1 Once injury incidence has been established, coaches must also consider the  
2 severity of each injury in order to prioritize interventions (79). If only the  
3 incidence is considered, coaches may mistakenly prioritize the prevention of  
4 injuries that have a high frequency rate, yet lead to little time-loss from training  
5 and competition. Instead, injuries that occur frequently and are associated with  
6 an increased severity should be the major focus of screening assessments and  
7 injury prevention training programs to minimize days-lost that could be used for  
8 athlete development.

9

10 Severity of injury should also be considered in relation to the nature of the injury  
11 (79), specifically as it relates to the type of tissue injured and the degree of  
12 damage (i.e. grade I vs. III muscle strain). As muscle tissues receive a greater  
13 blood supply than ligaments, tendon and cartilage, healing rate is expected to  
14 be superior (58). As such, the prevention of ligament injuries may be prioritized  
15 over muscle injuries if all other factors are equal. Severity may not only impact  
16 the time-loss from sports training and competition, but also the demand for  
17 treatment, cost of injury, as well as the potential for permanent damage that  
18 may impact the athlete's long-term health (79). All variables should be factored  
19 into the decision-making process in order to prioritize the development of a  
20 relevant testing battery and implementation of a targeted training intervention.

21

## 22 **STEP 2: IDENTIFY INJURY MECHANISMS AND RISK FACTORS**

23

### 24 ***Mechanisms***

1 Once injury incidence and severity has been identified, S&C coaches may  
2 begin to examine each injury and its accompanying mechanism. This will  
3 involve biomechanical screening of movement patterns, which is indicative of  
4 sporting situations that are characterized by increased injury risk (38). For  
5 example, in sports where anterior cruciate ligament (ACL) injuries are  
6 prevalent, activities involving rapid decelerations, such as changing direction  
7 and landing from a jump, should be assessed (38, 67). Dysfunctional  
8 movement patterns displayed during these activities involving positions of  
9 heightened knee abduction will increase the strain on the ACL (41). If possible,  
10 this should be verified with prospective cohort studies that show athletes who  
11 exhibit these aberrant movement strategies increase their risk of injury (25).

12

13 Coaches should be aware that not all injuries have a definitive mechanism.  
14 Overuse type pathologies, such as tendinopathy, are more likely to occur  
15 through the application of an unaccustomed and excessive training load (16).  
16 Many overuse injuries do have an associated movement pattern as it relates to  
17 a specific sport. For example, patellar tendinopathy in a male volleyball player  
18 is likely related to jumping activities (50), with landing strategies using greater  
19 knee flexion increasing patella tendon loading (21). Therefore, mechanisms of  
20 injury and risk factors should be considered alongside the demands of the sport  
21 and a comprehensive monitoring program to more accurately determine the  
22 athlete's injury risk at any given time point.

23

24 ***Risk Factors***



1 Injury risk factors can be characterized as either intrinsic or extrinsic (79).  
2 Intrinsic risk factors relate to the individual in question: age, maturation, sex,  
3 genetics, anthropometric measurements, health status, injury history, biomotor  
4 qualities (e.g. maximal strength) and training background (8, 79). These factors  
5 can then be used to individualize the injury prevention model to the athlete.  
6 Extrinsic risk factors relate to environmental influences: equipment, playing  
7 surface and weather (8, 79). Risk factors can be further divided into modifiable  
8 (e.g. the athlete's maximal strength levels) and non-modifiable (e.g. the  
9 athlete's gender) (7). Although non-modifiable risk factors are important for  
10 coaches to recognize in order to estimate risk, this information is not useful in  
11 the development of a test battery. However, identifying modifiable risk factors  
12 is vital in order to more accurately assess the athletes risk of sustaining injuries  
13 that are relevant to their sport (8).

14

15 Importantly, coaches should not view each risk factor as an isolated variable  
16 that predisposes an athlete to injury. Instead, the complex interaction and  
17 summation of each factor should be acknowledged, which results in an athlete  
18 being more vulnerable to injury (8). For example, an athlete displaying a risk  
19 factor during a screening does not necessarily indicate the athlete will get  
20 injured. It is the exposure to the mechanism that will provide the stimulus, in  
21 conjunction with other known risk factors that make injury a possible outcome  
22 (8). As such, an athlete who presents with poor eccentric hamstring strength  
23 possesses a functional deficit that may increase the risk of hamstring strain  
24 (78). In some instances, this may not be a major concern for the S&C coach if  
25 no other risk factors are present in the athlete's profile, or the athlete is not

1 exposed to high speed running as part of their training or competition. However,  
2 if the athlete was also a male, with a previous history of hamstring strain and  
3 competes in a sport where high speed running is routinely performed (55), weak  
4 hamstring musculature may become a primary concern for the S&C coach.  
5 Coaches must therefore perform a comprehensive risk factor analysis for each  
6 individual, considering all variables that may predispose the athlete to injury.

7

### 8 **STEP 3: DESIGN AND IMPLEMENT A VALID AND RELIABLE TEST** 9 **BATTERY**

10 In designing a test battery to identify athletes who display a greater risk of injury,  
11 coaches must select tests and procedures that are both valid and reliable (25).  
12 Examining the available literature or conducting investigations in the field would  
13 establish the reliability and validity of their testing protocols. There are currently  
14 a range of field-based tests that may be employed to screen athletes for  
15 modifiable risk factors such as hamstring strain (27), ACL injuries (66), shoulder  
16 and elbow injuries (71), lateral ankle sprain (62), and low back pain (51). As  
17 such, a number of options are available to the S&C coach that allows for the  
18 collection of valid and reliable data for identifying functional deficits in  
19 modifiable risk factors.

20

21 Once tests that assess relevant and modifiable risk factors have been selected  
22 and performed, an athlete profile can be established. Following the completion  
23 of the testing battery, the S&C coach can rank and prioritize deficiencies that  
24 may be identified, which will provide an approximate estimate of the athlete's  
25 injury risk. This can be accomplished by comparing the athlete's performance

1 with normative data that may be obtained within the literature on similar athletic  
2 groups.

3

#### 4 **STEP 4: PRIORITIZE AND IMPLEMENT INTERVENTIONS**

5 Research has shown the effects of targeted training programs on modifiable  
6 risk factors, with concomitant reductions in the occurrence of injury (44)  
7 including hamstring strains (4), ACL injuries (61), ankle sprains (54), shoulder  
8 pathology (3), and low back pain (17). Furthermore, well-designed injury  
9 prevention strategies have been shown to reduce the total number of injuries  
10 in sports such as soccer (43), basketball (22), and distance running (81). At this  
11 point, coaches should prioritize the goal of their interventions based on the  
12 athlete's deficits as measured in the testing battery, as well as their estimated  
13 overall risk as identified in step 1. Coaches should also ensure that  
14 performance objectives are not neglected. From this perspective, a multi-  
15 faceted approach should be adopted, discussed, and agreed with the athlete,  
16 coaching, and medical staff.

17

#### 18 **STEP 5: RETEST TO ASSESS THE EFFECTIVENESS OF THE TRAINING** 19 **INTERVENTION**

20 Following a period of training, coaches should retest the athlete in order to  
21 assess the effectiveness of the intervention and reevaluate the athlete's injury  
22 risk. This time-frame is dependent on the physical quality or skill being  
23 developed, and realistic expectations as to when adaptations should have  
24 occurred. For example, changes in ankle dorsiflexion range of motion are  
25 possible following a single exposure to a mobilization intervention (37, 42);

1 however, improvements in fundamental movement patterns and muscle  
2 architecture may take weeks to transpire (1, 10). Since changes in mobility  
3 could be more immediate, retesting can take place directly after the application  
4 of a single bout of mobilization. However, if motor control or structural changes  
5 are desired, then testing sessions should be separated by a number of weeks  
6 in order to observe appreciable changes.

7 Scheduling regular opportunities to retest should be seen as an evolving  
8 process, with the injury prevention model being continually redeveloped as  
9 updated research is published. Other factors may also lead to the evolution of  
10 the injury prevention model, such as modifications to the sport itself that alter  
11 the demands placed on the athlete (i.e. rule changes) and new experiences  
12 that influence the coaches understanding of the potential injury risk. Likewise,  
13 as the athlete's level of injury risk will change based on their physical  
14 development, the model will require alterations. This may be driven by a  
15 number of factors, such as an injury being sustained, growth and maturation or  
16 advancing age that is placing them at a greater risk for certain types of injury  
17 (i.e. hamstring strains (31)).

18

## 19 **DESIGNING THE INJURY PREVENTION MODEL**

20 To illustrate how the model and conceptual framework presented in this article  
21 can be applied, a case study example has been included in figure 2. The  
22 selected athlete is a 23-year-old male triple jumper, competing at international  
23 level. Injury rates during the course of multiple seasons in track and field have  
24 been shown to be a key determinant in an athlete's success (69). Track and  
25 field events present athletes with a high injury risk across the course of the

1 season, with an injury occurrence rate between 3.1 to 169.8 injuries per 100  
2 athletes depending on the event (18). For the men's triple jump event  
3 specifically, Alonso et al. (2) recorded 125 injuries occur per 1000 athletes  
4 within the competitive period.

5

6 Due to the nature of triple jump, acute injuries are a common occurrence when  
7 compared to distance events (20). The majority of these injuries occur in the  
8 lower extremity (2). In particular, thigh strains account for 22.8% of all injuries  
9 in jumping events (23), with hamstring strains being the most common (19).  
10 Ankle injuries are also widespread (22.7%), with sprains particularly prevalent  
11 (23). Achilles tendinopathy has also been shown to be prevalent in athletes  
12 competing in explosive events within track and field (18). Other sites of injury  
13 for jumping events are the trunk (13.6%), knee (12.1%) and foot (10.6%) (23).

14

15 Regarding the severity of injuries, the greatest time loss following injuries  
16 incurred from track and field events has been reported with hamstring strains  
17 (2, 23). Other injuries in athletics that have been shown to lead to large periods  
18 of time away from training and competitions (>4 weeks) include achilles tendon  
19 injuries, ankle sprains, strains at the groin and lower leg, as well as lower leg  
20 stress fractures (2). Based on injury incidence and severity presented here,  
21 hamstring strains, ankle sprains and achilles tendinopathy should be prioritized  
22 for the development of injury prevention strategies. As the available literature  
23 indicates that hamstring strains are the most common (19) and display the  
24 greatest severity (2, 19), a systems-based model will be applied herein to  
25 illustrate its application.

1

2 Modifiable risk factors for hamstring strains include considerations centred on  
3 flexibility, core stability, strength, and muscle architecture (55). Although local  
4 flexibility of the hamstring musculature is poorly associated with injury risk (4),  
5 reduced hip flexor (32) and ankle mobility (31) has been identified as potentially  
6 problematic. This is due to poor hip extension and ankle dorsiflexion mobility  
7 interfering with sprint mechanics by increasing hamstring length on the  
8 contralateral extremity during the terminal swing phase leading to malalignment  
9 of the pelvis (11), and disrupting ankle proprioception (31), respectively.  
10 Likewise, the trunk musculature has also been shown to prevent excessive  
11 lengthening of the hamstrings by controlling the sagittal plane orientation of the  
12 pelvis during the terminal swing phase of sprinting (11). Deficits in core stability  
13 therefore, has been suggested to increase the risk of hamstring injury during  
14 sprinting (55).

15

16 As the hamstring musculature are required to contract while lengthening during  
17 the terminal swing phase of sprinting (65, 77), eccentric strength tests are  
18 recommended for screening. This is supported by evidence that low eccentric  
19 hamstring strength has been shown to increase the risk of developing  
20 hamstring injuries in Australian football players (64). Eccentric hamstring  
21 strength may also provide valuable information regarding the architectural  
22 make-up of the hamstrings, as athlete's with short fascicles in their biceps  
23 femoris have been shown to possess poor eccentric strength (78). Reduced  
24 fascicle length is hypothesized to increase hamstring strain risk, by cause an

1   overstretching of the hamstrings whilst they are contracting eccentrically during  
2   the terminal swing phase (78).

3

4   As the hamstrings are both knee flexors and hip extensors, testing hamstring  
5   strength with a focus only on knee flexion is potentially problematic as it ignores  
6   their biarticular function (55). Therefore, it is suggested that hamstring strength  
7   be tested with both knee flexion and hip extension based tests. This  
8   recommendation is supported by Sugiura et al. (75), who highlighted hip  
9   extensor strength as a risk factor in elite sprinters.

10

11   Figure 2 shows a sequential flow, whereby the injury risk is established and  
12   followed by identification of mechanisms and modifiable risk factors. Relevant  
13   tests have then been selected, which may be used to identify deficits in the  
14   modifiable risk factors discussed. Each of the tests selected in figure 2 are  
15   reliable enough to recognise a functional change and are associated with injury  
16   (6, 12, 30, 47, 48, 63, 64, 75). Although some of these tests included may  
17   require access to expensive equipment, coaches can either find more cost-  
18   effective alternatives or develop their own tests as part of their own practice.  
19   For example, if the S&C coach does not have access to an isokinetic  
20   dynamometer, the single leg hamstring bridge may be an effective substitution  
21   in order to measure hip extension strength (27). However, if novel assessments  
22   are implemented and/or adapted to meet the needs of their environment, it is  
23   recommended that their reliability should be examined with their own athletes.  
24   This is to determine a 'true' change in performance can be accurately  
25   quantified, which falls outside of the typical error associated with the test.

\*INSERT FIGURE 2 HERE\*

Once deficits have been identified based on the athlete's test scores, a training intervention can be designed and implemented. It is encouraged that coaches adopt evidenced-based training strategies. For example, data have shown hip extensor strength (13), eccentric hamstring strength (56), core stability (73) and flexibility (80) can all be improved following targeted training programs. Figure 2 provides some general suggestions for exercises that may be used to reduce the modifiable risk factors related to hamstring strains. This approach will allow S&C coaches to develop an individualized training process for each athlete seeking to reduce identified and modifiable injury risk factors, which in turn will maximize training transfer and effectiveness.

Table 1 illustrates how such exercises may be integrated into a training program for the triple jumper who presents with poor eccentric hamstring strength during testing. This program attempts to improve multiple qualities such as explosive and maximal strength of the leg extensors in order to enhance sports performance, while developing hamstring eccentric strength to reduce injury risk. In order to improve the transfer of training by developing the rate of force development of the posterior chain musculature during eccentric contractions, table 2 shows a training program that could be incorporated in the triple jumper's weekly regime. For the interested reader, descriptions for how to perform many of these exercises are included in Sherry et al. (72).



**\*INSERT TABLE 1 AND 2 HERE\***

Furthermore, if myofascial or articular restrictions were identified during testing, Table 3 provides an example program that would develop that triple jumper's mobility. This program could be prescribed as a standalone training program, or integrated into a thorough warm up prior to the performance of dynamic activities that ensure the athlete is prepared for the high intensity nature of training. In these examples, each program would be carefully distributed around the athlete's technical training in order to achieve the goal of improving sports performance. Additionally, technical, nutritional, and psychological components would also be considered as part of a multifaceted high-performance approach to injury risk reduction that would include a thorough monitoring process.

**\*INSERT TABLE 3 HERE\***

## SUMMARY

While S&C coaches should always strive to improve sports performance, equal efforts must be made to reduce the risk of injury for each athlete. This article provides a step-by-step, systems-based model for designing injury prevention training programs. An evidence-based approach should form the foundation and the individual athlete should also be placed at the centre of the model. The current model aims to reduce modifiable risk factors through the incorporation of targeted training interventions, with the desired outcome of decreasing the athlete's overall injury risk.

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1 **Figure 1.** Step process for developing injury prevention training strategies to  
2 reduce injury risk.

3

4 **Figure 2.** Injury prevention process specific to reducing hamstring strain risk  
5 for an international male triple jumper.

6

7 **Table 1.** Example training program aimed at improving sports performance and  
8 reducing modifiable risk factors that are associated with hamstring strains.

9

10 **Table 2.** Example program aimed at improving coordination and rate of force  
11 development of the hamstring musculature.

12

13 **Table 3.** Example mobility program aimed at reducing modifiable risk factors  
14 that are associated with hamstring strains.

15