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Evaluation of a Novel ACL Injury Prevention Technique:

Can Martial Arts Fall Training (Break-Falling and Rolling) Alter the Lower Extremity At-Risk Biomechanics in Soccer Athletes?

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Abstract

Introduction: ACL injuries have remained prevalent despite injury prevention interventions. We propose approaching injury prevention from a novel angle by implementing martial arts falling techniques such as break-falling and rolling.

Methods: Four athletes (ages 9 to 17, both sexes) from a premier soccer team were recruited to participate in this pilot study. All subjects continued their usual training and partook in twice weekly interventional training of martial arts fall training for ten weeks, taught by a 5th degree black belt

master in karate and aikido. Baseline and post-intervention proprioceptive testing was performed in the Quinnipiac Biomechanics Laboratory using the Neurocom Balance Master system. A mixed factorial ANOVA model was used to determine the effects of intervention training on the proprioceptive variables of interest.

Results: There was a significant decrease in the mean impact index for the right lower extremity, which measures the control of impact force descending onto the swing leg during the "Step Up and Over" test. Additionally, increases were noted for mean equilibrium in five of six testing conditions.

Conclusions: The results of the mean impact index test highlight the efficacy of martial arts fall training in the dominant lower extremity. The trend of improvement in the dominant leg in a variety of proprioceptive metrics suggests that the intervention reinforced the more honed neural pathways of the dominant side quicker than that of the non-dominant. Finally, the overall increase seen in mean equilibrium is promising for a pilot study with such a short intervention period.

Keywords

ACL injury, martial arts fall training, karate, aikido, biomechanics, injury prevention

Introduction

An estimated 100,000-250,000 individuals suffer an anterior cruciate ligament (ACL) injury nationally each year (1). As a result of these injuries, nearly 350,000 reconstructions are performed annually, making it the largest single problem in orthopedic sports medicine (2). ACL injuries result in high financial burden, lengthy rehabilitation, lasting physical and psychological effects, risk of reinjury, and potential development of osteoarthritis (3). These potentially life-long post-injury consequences highlight the need for effective ACL prevention interventions.

The majority of ACL injuries (60% for women, 41% for men) occur during non-contact episodes due to directional changes such as cutting maneuvers and jump landings, which lead to shearing forcing on the ACL (4, 5). Although various methods have been implemented in attempts to train athletes to avoid ACL injury, to our knowledge, none have incorporated martial arts falling techniques. One such technique, "break-falling," involves dispersing the impact forces from falling by using the arm, and more importantly, rolling while landing. In doing so, athletes decelerate their falls and orient themselves into a more advantageous posture as they hit the ground. Groen et al found that such martial arts falling techniques can reduce impact force by 27.5-30% (6). These techniques could be applied outside of martial arts, such as in soccer or other sports played on soft surfaces like grass. An intervention program utilizing these techniques and other proprioceptive training could help athletes by increasing their kinesthetic awareness and giving them new options for falling and other dangerous maneuvers.

While studies using martial arts falling techniques for injury prevention in sports have not been conducted, there have been studies to determine their efficacy in lowering hip fracture rates in the elderly. Two studies using subjects with martial arts backgrounds found reduction in force of impact on the hip with martial arts falling techniques compared with a 'block' technique (blocking the ground with an arm, a natural falling response) (7,8).

Nessler et al conducted a review of programs attempting to lower ACL injury risk and found that neuromuscular and strength training at a young age showed the most promising results in injury prevention (2). The degree of neuromuscular function (vestibular, proprioceptive, reaction times, etc.) in athletes has been identified as a key factor in the assessment of recovery after acute ACL reconstruction (9). This study seeks to use a neuromuscular assessment to identify if there are

differences between athletes that impact their ability to avoid injuries, such as those related to falls. Additionally, the assessment seeks to determine if differences in neuromuscular function effect athletes' ability to adopt new techniques to avoid injury. Using existing validated and reliable testing such as the NeuroCom Balance Master may be able to identify such differences. The Balance Master® system (from NeuroCom International, Inc, Clackamas, OR, USA) assesses a subject's balance correction by using a dynamic force plate with rotation capabilities and a dynamic visual surround, quantifying the vertical forces exerted through the subject's feet when the plate suddenly rotates or when the dynamic visual shifts in place. Additionally, it measures center of gravity position to assess postural control during these changes. This information can be used to quantify stability with visual and sensory biofeedback in dynamic environments. We sought to evaluate the athletes by identifying baseline balance and reaction deficits and potentially beneficial changes following martial arts fall training.

Given the absence of research utilizing martial arts falling techniques in other sports and the lack of current ACL injury prevention programs effectiveness, this study aims to compare lower extremity biomechanics and risk factors in soccer athletes with fall training compared to those who do not receive this novel injury prevention training.

Methods: The subjects are members of a Connecticut premier soccer club that were recruited to participate in this pilot study. To enroll in the pilot study, subjects needed to be free of injury, have no prior knee ligament surgeries, have no prior break-falling training, and have no known adhesive tape allergy.

All subjects continued their usual soccer training and partook in the 10-week interventional martial arts fall training taught by a 5th degree black belt master in karate and aikido (**Appendix B**). The intervention was performed twice weekly in addition to usual training (**Appendix A**) for ten weeks. Baseline and post-intervention proprioceptive testing was performed in the Quinnipiac University Motion Analysis and Biomechanics Lab using the Neurocom Balance Master system (**Table 1**).

A mixed factorial ANOVA model was used to determine the effects of the intervention training on the kinematic, kinetic, and EMG variables of interest. The between subjects factor was treatment group (intervention and control) and the within subjects factor was time point (pre-intervention and post-intervention). The test of the interaction between group and time point determined if the intervention produced change in the variables of interest greater than seen in the control group. The alpha level of significance for this study was set at the 0.05 level.

Results: Five subjects were originally enrolled in the pilot study and met all inclusion and exclusion criteria. One subject only completed pre-intervention testing and as a result, was excluded from the final data analysis. The four subjects in the pilot study were two females and two males. Subjects ranged in age from 9 to 17 years old with an average age of 12.75 years and a standard deviation of 3.03.

In the step up and over test, there was a significant increase in mean movement time from pre to post (Pre_{mean}=1.14, $Post_{mean}$=1.94, p=.03 **(Figure 1**) martial arts training. While not statistically significant, downward trends were observed in the right lower extremity for mean turn time (step-quick turn test), mean turn sway velocity (step-quick turn test), and mean sway energy (unilateral stance test) (**Figure**

3). There was a non-statistically significant decrease in the impact index (Pre_{mean}=46.3, $Post_{mean}$=36.9, p=.206) as well (step up and over test).

Discussion: In this pilot study, we examined the relationship between martial arts fall training and neural pathway function as a means to prevent ACL injury. As of today, ACL injury prevention training has been largely unsuccessful. This is likely because the majority of ACL injuries occur during noncontact episodes, suggesting that the issue lies in the nervous system and its control of the body in space as opposed to lower body strength or conditioning. To address this, we took a novel approach to the problem by integrating both the vestibular and proprioceptive systems into our training.

During the step up and over test, the mean movement time had a statistically significant increase comparing pre and post martial arts fall training. Considering our low sample size, this was a significant finding and suggests efficacy of martial arts fall training on neuromuscular (vestibular, proprioceptive, reaction time, etc.) function and thus a promising component of future ACL injury prevention programs. Additionally, the general improvement in multiple metrics (mean turn sway, mean turn time, and mean impact index) were seen only in the dominant (right) leg of the subjects. These findings may suggest that the more honed neural pathways of the dominant side are more receptive or have a lower response threshold to neurocognitive training. Further research with either longer or greater number of training sessions would be needed to further examine this relationship, as well as investigate the threshold at which the non-dominant side could recoup the gains in the dominant side.

Additionally, an increase in mean equilibrium in five out of six conditions was observed (**Figure 2**). Unlike the specificity of one leg versus the other, this supports a more global effect of martial arts fall

training on the integration between the nervous system and control of the body in a variety of settings; from eyes open to closed, stable foundation to a moving one, and still surroundings to shaking ones. A similar study, but with a larger number of subjects would be helpful in determining the true impact of martial arts fall training on the vestibular and proprioceptive systems. Finally, a stepwise decrease in mean sway energy with the toes in the upward position was apparent (Figure 3). This trend is promising as it highlights one of the driving reasons for our novel approach toward ACL injury prevention: adaptability. Seeing subsequent decreases in sway energy at each iteration prompts the notion that martial arts fall training may help the body anticipate and adapt to sudden and unexpected positions. Since the majority of ACL injuries happen during sudden or unexpected changes in body positioning, this observation is one of the most promising aspects of our data and one that encourages future inspection into martial arts fall training intervention.

Our study's major limitations include its small sample size and the nature of pilot studies. Other limitations include the few number training sessions and subject variability (age, sex). However, it is crucial to stress the value and indispensability of pilot studies like ours. Fewer subjects offer a cost-effective stratagem to probe hypotheses in a quick manner. Future study should involve a larger sample size and ideally a randomized-control trial to generate more robust data for future intervention strategies.

Conclusion

Martial arts fall training is a promising avenue for ACL injury prevention. In our study, a statistically significant difference in mean movement time in the right low extremity suggests improved neuromuscular function. The trend of improvement in the dominant leg in a variety of proprioceptive metrics suggests that the intervention reinforced the more honed neural pathways of the dominant side

quicker than that of the non-dominant. Increases in mean equilibrium and mean strategy is promising for a pilot study with such a short intervention period and suggests future study.

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Figures and Tables

Table 1: SMART Balance Master® Tests. The SMART Balance Master® utilizes a dynamic force plate with rotation capabilities to quantify the vertical forces exerted through the patient's feet to measure center of gravity position and postural control; and a dynamic visual surround to measure the patient's use of visual information to maintain balance. It provides assessment and retraining capabilities with visual biofeedback on either a stable or unstable support surface and in a stable or dynamic visual environment.

Test	Description
Step Up and Over (SUO)	The SUO quantifies motor control characteristics as the patient steps up onto a curb with one foot, lifting the body through an erect standing position over the curb, swings the other foot over the curb, and then lowers the body to land the swing leg on the force plate. Measured parameters are rising index (force to rise), movement time, and impact index (control of impact force descending onto the swing leg).

Figure 1: Mean movement time pre-intervention and post-intervention for left and right lower extremities.

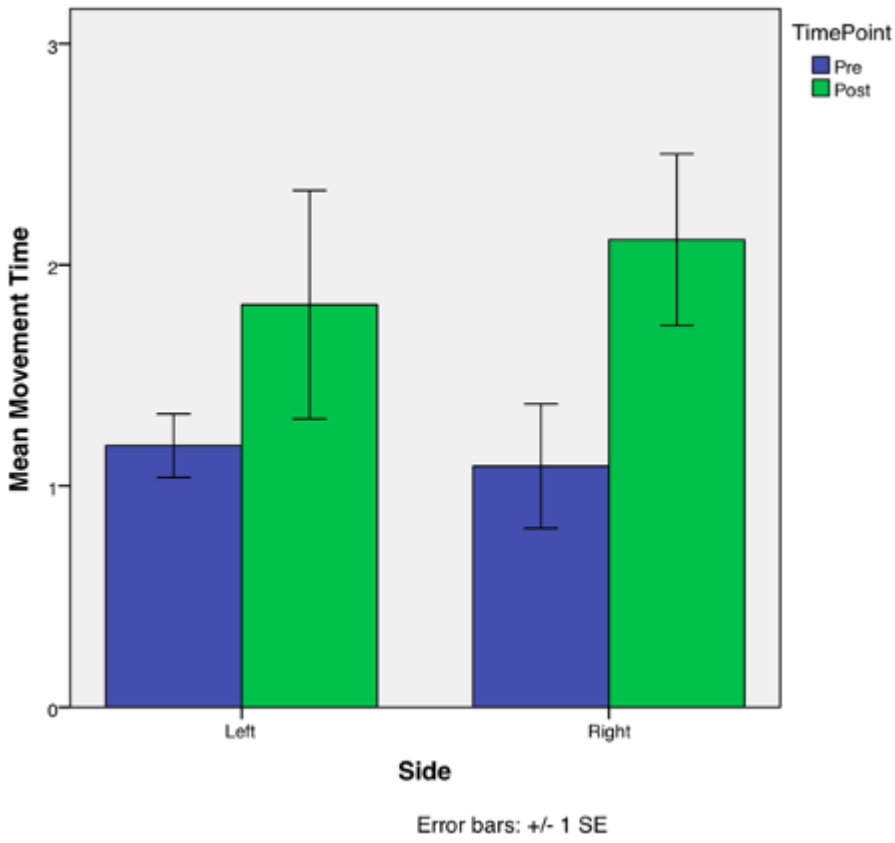


Figure 2: Mean equilibrium pre-intervention and post-intervention.

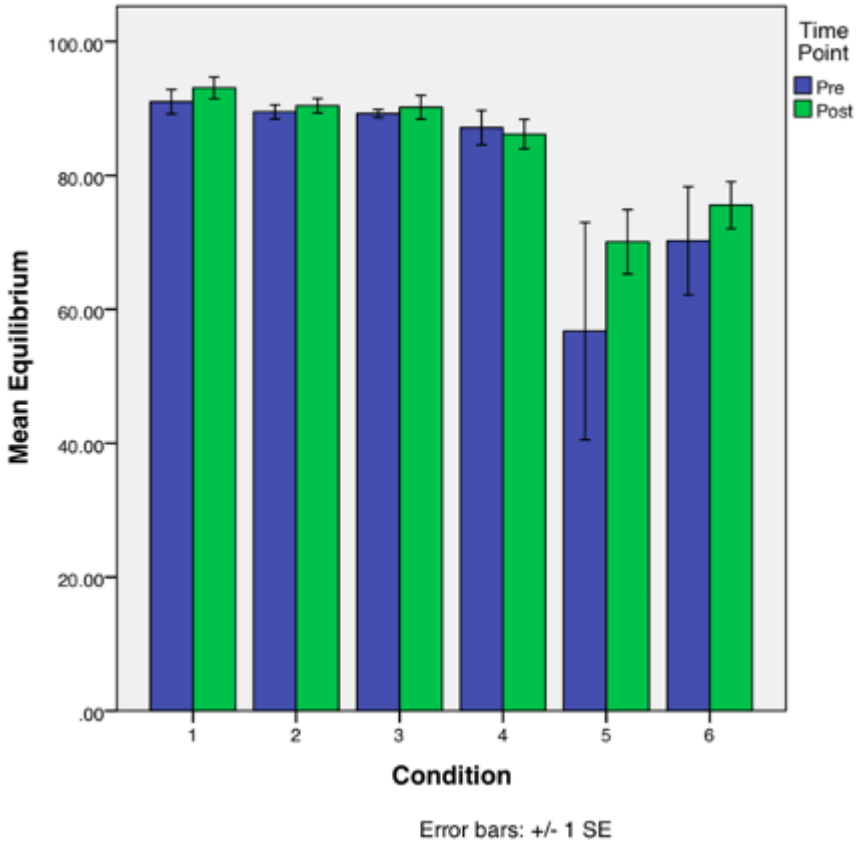
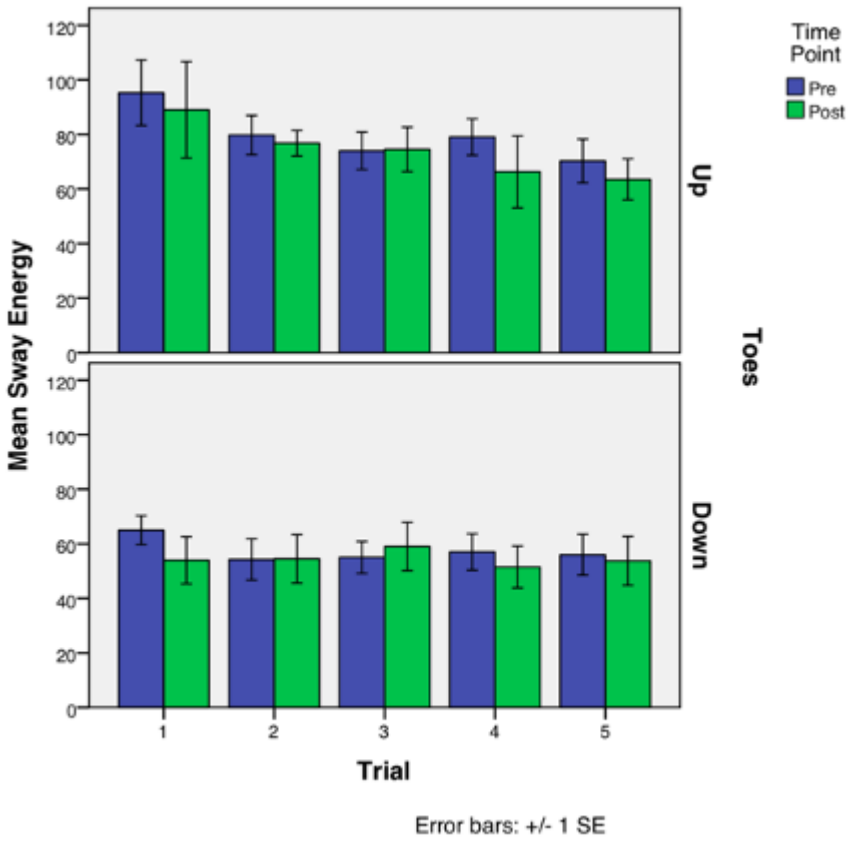


Figure 3: Mean sway energy pre-intervention and post-intervention for toes in the up and down position.



Appendix A: Usual training for U14 Female Soccer Athletes

Monday:

Conditioning - Stride 6 x 100 yards with 24 second rest, 6 x 80 yards with 18 second rest, and 6 x 60 yards with 12 second rest.

Intensive interval with the ball: 3v3 or 4v4 - 3x8 minutes with 2 minutes rest between sets

Tuesday:

Power - Plyometrics - Repeat Tuck Jump 3-5 sets x 5 reps.

Explosive speed - Spring 10 x 20 yards - 20 to 30 second rest between reps

Extensive interval: 7v7/8v8 - 2 x 20 minutes with 2 minutes rest between blocks

Thursday:

Agility - Speed ladder - Different variations in order to increase speed and coordination

Conditioning - Individual dribbling in combination with skills for 12 minutes - no rest

Saturday:

CrossFit for DFA players in order to work on strength and power increase, consisting of individual resistance training.

Appendix B Martial Arts Based ACL Injury Prevention Program

Table 1: Shown in this table are the planned exercises for the intervention program. Each training session is divided into three primary components: general proprioceptive training, general exteroceptive training, and sport-specific *ukemi-waza* (falling and rolling techniques taught in the martial arts). The details for each section are as follows:

Table 1:

Phase	Exercises	Duration
Weeks 1-3	Proprioceptive Training *3 repetitions, Standard Speed* Lunge Positions – Neutral Foot Lateral/Medial Ankle Tilts 3 Position Toe Pulls Closed-Chain Knee Circles – Anterior Lunge Closed-Chain Hip Circles – Anterior Lunge Peg Board Drill	5 Minutes
	Exteroceptive Training Vestibulospinal Reflex Drills – Narrow Stance *1 repetition each each direction* Vestibulo-ocular Reflex Drills *3 repetitions each direction* Hand Chasing – Foveal and Peripheral Version *20 seconds per repetition for 3 repetitions per person* Saccades – Horizontal and Vertical *10 repetitions each direction*	10 minutes
	Ukemi-Waza *5 repetitions per side* Kneeling Side Fall Kneeling Forward Fall Kneeling Forward Roll Kneeling Backward Roll Jump Landing Training – Neutral Stance Off ground acceleration	15 minutes

Weeks 4-6	Proprioceptive Training *3 repetitions, Coordinated Speed* Lunge Positions – Toes In, Toes Out Lateral/Medial Ankle Tilts 3 Position Toe Pulls Closed-Chain Knee Circles – Lateral Lunge Closed-Chain Hip Circles – Lateral Lunge Peg Board Drill	5 minutes
	Exteroceptive Training Vestibulospinal Reflex Drills – Lunge Stances *1 repetition each each direction* Vestibulo-ocular Reflex Drills *3 repetitions each direction* Hand Chasing – Foveal and Peripheral Version *20 seconds per repetition for 3 repetitions per person* Saccades – Horizontal and Vertical *10 repetitions each direction*	10 minutes
	Ukemi-Waza *5 repetitions per side, starting from a stationary position* Side Fall Forward Fall Forward Roll Backward Roll Jump Landing Training – Lunge Stances Off ground acceleration	15 minutes
Weeks 7-10	Proprioceptive Training *3 repetitions, Sports Speed* Lunge Positions – Neutral, Toes In, Toes Out Lateral/Medial Ankle Tilts 3 Position Toe Pulls Closed-Chain Knee Circles – Posterior Lunge Closed-Chain Hip Circles – Posterior Lunge Peg Board Drill	5 minutes

	Exteroceptive Training Vestibulospinal Reflex Drills – Single Leg Stance *1 repetition each each direction* Vestibulo-ocular Reflex Drills *3 repetitions each direction* Hand Chasing – Foveal and Peripheral Version *20 seconds per repetition for 3 repetitions per person* Saccades – Horizontal and Vertical *10 repetitions each direction*	10 minutes
	Ukemi-Waza *5 repetitions per side with momentum* Side Fall Forward Fall Forward Roll Backward Roll Jump Landing Training – Single Leg Off ground acceleration	15 minutes

Proprioceptive Training

* The athletes will be performing a selection of drills from the Z-Health Performance Solutions R- and I-Phase joint mobility series.

* Athletes will be encouraged to precisely explore end ranges of motion for a selection of lower body joints in order to create clearer somatosensory and motor maps.

* Athletes will be taught how to create better sensory and motor differentiation between joints.

* Athletes will be taught how to assess for excessive nociception during the exercises.

* Athletes will be progressed over the course of the study from performing the drills at a Standard Speed (5-15 seconds per repetition) to a Coordinated Speed (1-8 seconds per repetition) to a Sports Speed (0.5 to 2 seconds per repetition).

* Purpose 1 of the drills is to create better precognitive awareness of when joint movement has been exhausted and a fall must be initiated.

* Purpose 2 of the drills is to reduce nociceptive activity in the lower body joints and prevent arthrokinetic reflexes from reducing motor control.

Exteroceptive Training

* The athletes will be performing drills to train the visual and vestibular systems.
* The exercises for the vestibulospinal reflex will involve closing the eyes to remove the input from the visual system and then using a variety of stances and head movements to challenge the athlete's balance. Stances will progress from a narrow stance with feet together to lunge positions to single leg holds. The head movements will involve neck rotation to stimulate the horizontal semicircular canals, neck lateral flexion to stimulate the anterior and posterior semicircular canals together, and neck flexion or extension to stimulate the anterior canals or posterior canals, respectively. End-range head positions will be held for 10 seconds, and the athletes will be tasked with keeping their balance during that time.
* The exercises for the vestibular-ocular reflex will involve fixating the eyes on a central target while performing neck rotations or neck flexion and extension movements.
* Hand chasing is a partner drill that requires the athlete to follow a partner's hand with her own without letting the hands touch. The foveal version requires the athlete to follow the partner's moving hand with both her hand and her eyes, thus training the smooth pursuit system, and the peripheral version requires the athlete to follow the partner's hand with her hand while fixating her eyes on a central target, thus training peripheral awareness.
* Saccade drills will be performed with a partner giving peripheral cues for an athlete to saccade her eyes to a target. Horizontal and vertical saccades will be utilized to stimulate both the mesencephalon and pons.

* Purpose 1 of the exteroceptive drills is to create a better precognitive awareness of when the vestibulospinal reflex is insufficient to maintain balance and a fall must be initiated.
* Purpose 2 of the drills is to improve gaze stability and allow the athletes to orient their vision quickly while falling or rolling.
* Purpose 3 of the drills is to enhance the athlete's awareness of her surroundings and of when a fall might need to be initiated or altered to avoid a collision.
* Purpose 4 of the drills is to ensure that the athlete's vestibulospinal and reticulospinal tracts are properly exciting or inhibiting the flexors and extensors of the knee and ankle.

Ukemi-Waza

* Ukemi-Waza are falling and rolling techniques taught in the martial arts so that training partners can be thrown or manipulated—the translation of ukemi is "receiving body"—without injury. Sometimes the ukemi is guided purely by the thrower, as in a typical hip throw, but other times the ukemi is initiated by the receiving partner herself in order to undo the pressure or torque from a joint lock or twist, saving that joint from damage.
* In addition to falling, athletes will also be taught how to get back up and expediently rejoin play.
* The athletes will be progressed from falling and rolling at a kneeling height to falling and rolling from a stationary standing position to falling and rolling from standing and already in motion.
* The athletes will be progressed from practicing the ukemi-waza on a matted surface to practicing them on their sport-specific playing surface.
* Purpose 1 of these drills is to offer the athletes additional options for how to deal with the forces their joints may experience during the course of their sporting movements.

* Purpose 1 of these drills is to reduce any hesitation to falling that may come from fear of impact or fear of being unable to rejoin play in a timely manner.