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DIFFERENCES IN LOWER LIMB KINETICS IN COLLEGE AGE FEMALE GYMNASTS TO COACHES' PERCEIVED EFFICIENCY IN A SPECIFIC COUNTER MOVEMENT JUMP TECHNIQUE

Stephen C. Avgerinos

23 Pages

This thesis reports the results of a quantitative research project which describes the kinetics of female collegiate gymnasts aged 18 to 21 performing a 'punching' counter-movement jump (CMJ) technique that is taught and required for exemplar scoring during NCAA competition. Twelve female gymnasts were recruited from the competitive team at Illinois State University. Participation was voluntary and athletes were not compensated. Each gymnast performed 8 punch-CMJ trials without coaching instruction except to perform a punching CMJ. The method of performing this CMJ began by stepping off from a 33 cm elevation, 'punching' off the force plates, and finishing with a landing on the same force plates, one foot on each plate. A 3-dimensional Vicon motion analysis system was used to collect kinematic data, and one force plate was used to collect ground reaction forces under the left limb during the jumps. Vertical ground reaction force and joint kinetics of the ankle of the left leg were obtained using inverse dynamic analyses.

The trials were observed and rated categorically from bad, not very good, decent, good and very good by a professional gymnastics coach. Changes between the categories for peak left ankle power (Lankle) and the peak left vertical ground reaction forces (LVGRF) were observed with a clear trend in increasing peak ankle power and increasing peak LVGRF with more efficient punch movement patterns. This indicates that coaching athletes to master this movement in order to perform it with high quality, will subject the ankle to higher ankle power, and higher LVGRF at impact.

KEYWORDS: Kinetics, Power, Ground Reaction Force, Counter Movement Jump

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A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

School of Kinesiology and Recreation

ILLINOIS STATE UNIVERSITY

2017

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DIFFERENCES IN LOWER LIMB KINETICS IN COLLEGE AGE FEMALE GYMNASTS TO COACHES' PERCEIVED EFFICIENCY IN A SPECIFIC COUNTER MOVEMENT JUMP TECHNIQUE

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CHAPTER I

INTRODUCTION

The vast majority of skills performed by female gymnasts originate from the performing surface and return to the performing surface. There are a very high number of repetitions performed by the athletes during the year as they learn new skills and practice them in order to successfully execute them in a competitive setting. During the course of a typical week, athletes can be in the gym training between 7 to 36 hours a week, depending on age and competitive level.[1] Top athletes may practice 5 to 6 hours a day, 30 to 40 hours a week, and may eventually amass 220,000 to 400,000 elements per year during the course of training and competition.[2] The high duration, repetition and intensity of this training may contribute to injury. Lower limb injuries account for over half of sustained by gymnasts during practice and competition.[3] Injuries to the Achilles tendon in particular can be devastating and result in excessive time away from training to recuperate. In the NCAA during the 2013-2014 season, there were at least 9 season ending Achilles tendon ruptures.[4] As of February 12, 2017, (the sixth week of the competitive NCAA season) there were already three confirmed Achilles tears.[5]

There have been numerous studies describing the traditional countermovement-jump landing techniques in WAG; and, these all demonstrate large loading values at the hips, knees and ankle .[6,7,8] However, countermovement-jump landing are only two of the three distinct lower limb motions involved in Women's Artistic Gymnastics (WAG). A punching takeoff is used on a large number of skills such as the floor and beam events; and, is the primary mechanism involved in the vault, both in the run up to the takeoff, and in the initial punch on the springboard to initiate height and rotation. The 'punching' takeoff is taught by experienced coaches to athletes very early in their career and is continued to be used by all levels of competitive gymnasts. When initially teaching the technique, coaches will use verbal cues such as 'be tight' and 'keep a tight shape' as well as cues to keep their legs straight and stretch when leaving the floor. The experienced coach looks for the athlete's ability to connect a combination of lower limb motions by impacting the surface between the skills with relatively straight legs and with as little time in contact with the performing surface. This infers a functionally 'stiff' or 'rigid' body position which would tend to create higher lower limb loading parameters. Subjectively and in addition to maintaining a rigid body position, speed of rebound, height off the floor, and the ability to control direction when punching are common characteristics a coach would use to delineate a good punch from a poor punch when evaluating athletes' skill in performing this motion. Given the reliance of the punch movement in WAG coupled with the high incidence of achilles tendon injuries in Wag athletes, it is important that coaches understand the biomechanics of this motion at the ankle. Yet, a literature review produced no direct assessments of the punch motion. Thus, the purpose of this study is to describe the ankle kinetics in good versus poor punch techniques as labelled by an experienced WAG coach. It is suggested that superior punch performances would be associated with higher LVGRFs and higher peak ankle powers which may help explain high incidence of ankle/achilles.

CHAPTER II

REVIEW OF THE PERTINENT LITERATURE

Participation in sport by female athlete has increased in participation dramatically since 1980. Since the inception of Title IX in 1972, participation in women's sports has roughly doubled every ten years. Participation in Women's Artistic Gymnastics (WAG) has shown similar growth, with participation at the high school level, the various levels involved in independent clubs, and the total number of those independent clubs all showing significant growth, as well as a noticeable spike in that increase immediately following the quadrennial Olympic Summer Games.[9]

During the course of a typical week, athletes can be in the gym training between 7 to 36 hours, depending on age and competitive level. For the average high school age gymnast training to attempt to get a scholarship (15-18 years old competing JO level 9 and 10 or competing in the elite program) the average number of hours training is 20.[2] Top athletes may practice 5 to 6 hours a day, 30 to 40 hours a week, and may eventually amass 220,000 to 400,000 elements per year during the course of training and competition.[2] This number has changed in the last ten years or so, with most club coaches actually decreasing the number of hours they are training their athletes in the gym from higher numbers a decade ago. The prevalence of injuries as well as gymnast 'burn out' has contributed to this.

The increase and participation, as well as the evolution of the difficulty of the elements performed in the sport make injuries a primary concern of coaches and athletes alike. The first step in understanding possible mechanisms of injury is to break down those events and examine what is required of the gymnasts.

In WAG, there are four events that the athletes perform. The vault consists of a run down a carpet bonded foam runway (approximately 65-80 feet depending on the athlete) followed by entry to the springboard, where the athlete punches off the board to initiate a series of flips, with contact between the athletes hands and the vault table being mandatory immediately following the punch off the spring board.

Landing upon completion of the vault is on either a 10 or 20 cm base mat, upon which the athlete may place additional mats as preferred, within constraints of the rules.

On the uneven parallel bars, the athlete will perform a skill to ‘mount’ the apparatus, possibly involving a punch off the springboard depending on the skill the athlete has chosen to use as a mount. The athlete will perform a number of circling skills around the rails of the apparatus, involving different rates of speed, changes in body shapes, changes in axial direction, and some of them involving a release of the rail completely with re-grip upon completion of that particular skill. The athlete will perform a dismount at the end of the routine usually involving a very strong swing and release of the rail involving a free salto that concludes with the athletes’ feet on the ground. As on the vault, a 10 cm or 20 cm base mat is involved, with additional matting as desired within constraint of the rules.

The balance beam is an event performed mostly upon the beam itself, which can be 120 cm or 125 cm from the landing surface (depending on competitive level). The beam itself is an aluminum core covered in a slight layer of foam and a synthetic leather outer covering. The beam may contain shock absorbing mechanisms depending on the manufacturer’s specification. This event can be particularly punishing on the athletes lower limbs. The routine begins when the athlete mounts the beam in the manner that she has selected from the code of points. She then performs a series of flipping, leaping, and jumping skills interspersed with dancing elements and her chosen choreography. A dismount is performed to conclude the routine, involving a takeoff from the beam and some form of short axis rotation and a landing on the surface, with a similar situation as the dismount on UB and the landing of the vault.

The final event is the floor exercise, where the athlete performs 2 to 4 tumbling passes as well as combinations of jumping and leaping elements combined with dance choreography matching a chosen selection of music. The event is performed on a spring floor, and some mats may be used on the ends of the tumbling passes (but not in the middle). It is generally preferred not to use matting during this event to show proficiency and mastery of the tumbling elements.

Looking at the four events, we see a large number of elements that involve taking off from and/or returning to the performing surface with a great deal of force. We must remember that these athletes perform these skills not only in competition, but these elements need to be taught initially and then practiced repeatedly in order to perform them in a safe manner. For example, gymnasts may need to perform dismounts in excess of 200 times a week.[10]

Even assuming perfect technique in execution of the skill and landing angles optimal for absorption of the forces involved, the athletes may be subjected to peak vertical ground reaction forces in excess of nine bodyweights and occurring in less than 0.05 seconds.[7] The technique involved in executing the landings can alter those forces greatly, with a 'soft' landing ('soft' and 'stiff' as defined by the "maximum knee flexion angles of greater than and less than 90 degrees from full extension, respectively" possibly changing the peak GRF by 33%. [11]

The technique most commonly performed (as it is a technique used to link skills together in combination, often increasing the potential score of the athlete), is a punching jump. As indicated by the name, it is a plyometric movement where momentum is redirected by exertion of the lower limbs. This technique is executed often in tumbling combinations by the gymnast, where they are attempting to maintain momentum through repeated contact with the floor (and sometimes a change of direction due to a turn on the long axis of their body during a salto (free flip around the short axis of the body). Speed and connection are important to successful execution, so a rigid upper body and fairly rigid lower body are important. In this technique the ankle (and the surface) are absorbing and redirecting the vast majority of the forces involved. The most forceful of these punches occur in tumbling passes as the takeoff for the ultimate salto in combination, and on vault when the athlete strikes the spring board taking off for their chosen skill. This particular counter movement jump has not been previously distinguished from other jump and landing techniques, or rigidly defined. The correlation of technique and injury in tumbling takeoffs has been studied[12] but not extensively.

Lower limb injuries account for 58 percent of injuries sustained by gymnasts during practice and competition.[3] Injuries to the Achilles tendon in particular can be devastating and result in excessive time away from training to recuperate. In the NCAA during the 2013-2014 season, there were at least 9 season ending Achilles tendon ruptures.[4] Achilles tendinopathy can occur as a result of simple overuse [13] and exacerbated in gymnasts as the result of inefficient technique or simply poor landing angles due to fatigue or mental mistakes [2].

Coaches are constantly concerned with physically preparing their athletes to execute the necessary skills, as well as taking steps to minimize damage to the athletes during the natural course of training. Efforts have been made to track and monitor the athletes in order to uncover possible relationships of parameters to performance, as well as help formulate strategies to minimize injury and 'burnout'. [13]

With a concern for injury and noting the high number of lower limb impacts involved in the sport, it is not surprising that lower limb injuries comprise the majority (approximately 61%) of injuries reported in a study of young, pre-collegiate gymnasts. Foot and ankle injuries alone account for 33% of those injuries. [9] In another study, lower limb injuries accounted for 58 percent of injuries sustained by gymnasts during practice and competition.[3] In a study of collegiate gymnasts, injuries to the knee, shin, ankle, and foot were prevalent when looking at both total injuries and new injuries sustained.[14] In the NCAA during the 2013-2014 season, there were at least 9 season ending Achilles tendon ruptures.[4]

In order to gain a better understanding of what is happening in the ankle and the Achilles, mechanics and structure must be examined. The gastrocnemius and the soleus muscles merge to form the Achilles tendon, and this can happen in one of two ways; type 1 (which is more common) exhibits the two aponeuroses joining 12 cm proximal to their calcaneal insertion. In type 2, the gastrocnemius aponeurosis inserts directly into the aponeurosis of the soleus. [15] While exact causes of tendinopathy are unclear, overuse is often cited as a large contributor. [3, 13] The Achilles is the largest and strongest tendon in the body, measuring approximately 15 cm in length and having an average thickness of 6 mm. Despite this and its relative strength, it is among the most frequently injured tendons in the body.[16] The Achilles changes over time and with use/overuse. These changes manifest in diminishing vascularity, and in the type of collagen present. Degenerated tendons can have significantly higher levels of type III collagen.[16] There is an undulating pattern to the fibrils. Stretching a tendon more than 2% will cause it to begin to lose its wavy configuration. Straining a tendon greater than 8% will result in macroscopic rupture. [15]

The amount of plantar flexion of the foot to absorb and/or redirect the forces involved in all of our conditions is one of the main concerns within this study. The cardinal muscles at work during plantar flexion are the gastrocnemius and the soleus, via the Achilles tendon. [16]

If we hold to Newton's three laws, then if the gymnast is taking 9 to 13 times their body weight on the landing, then at least that much force must be exerted on the takeoff to get the gymnasts body in motion. Due to the nature of the 'punching' CMJ technique, the Achilles tendon and the soleus and gastrocnemius are bearing the majority of the load, and they are doing it in a fraction of the time than a landing alone would take to be executed. These factors combined could indicate that the Achilles is sustaining serious punishment during this technique when compared to the landing or the jumping takeoff. It could also be compounded by 'whipping' of the heel, hyper-pronation of the foot, and secondary forces to the subtalar motion, because of its insertion to the calcaneus.

Traditional countermovement jumping and landing studies have been studied. [6,7,8,11,12] However, searching through the published literature reveals very little to no mention of the punching CMJ. If we are to gain a better understanding of the possible effects on the lower limbs in female gymnasts due to repeated execution of the punching CMJ, we must study the kinetics involved in the execution of this technique.

Minimizing overuse could be a very important step in protecting the athletes from lower limb injury in general, and in minimizing the chances of a rupture of the Achilles tendon. This study of the kinetics of this technique may answer the question of whether training athletes to achieve a proper punch take off is causing higher stresses at the ankle.

CHAPTER III

METHODS

Subjects and recruitment

12 Division 1 NCAA competitive gymnasts were recruited from Illinois State University. All subjects signed informed consent prior to participation. All subjects were female, ages 18 to 21, with bodyweight ranging from 58.5 kg to 76.2 kg (mean 67.3 kg ± 6.06 kg) and heights ranging from 149.8 cm to 172.7 cm (mean 163 cm ± 6.04 cm).

In order to attain accurate kinematic data, participants wore leotards (as they would at a normal practice session or competition in the gym). They were instructed to report to the biomechanics lab for a single data collection session. Participants were permitted to warm up with jogging and calisthenics and stretching as they deemed appropriate to participate in this study.

Instrumentation

Ground reaction force data were collected at 2000 Hz for all trials using a multi-axis force platform (Advanced Mechanical Technology, Inc., Watertown, MA). The top surface of the force platform was flush with a raised walkway. To obtain kinematics, thirty-seven 10-25 mm diameter reflective markers were then attached to anatomical landmarks on the hips, thighs, legs, and feet using athletic tape and/or rubber bands. Specifically, the markers were placed on the left (L) and right (R) shoulder, L and R ASIS, and the L and R PSIS. The 25 mm markers were placed on the L and R upper arm, L and R elbow, C7, T10, clavicle, Sternum, R scapula, L and R thigh, L and R knee, and L and R heel. The 19 mm markers were placed on the L and R forearm, L and R shank, L and R ankle, and L and R toe. The 14 mm markers were placed on the L and R anterior wrist, L and R posterior wrist, L and R finger, and 4 head markers. This model divided the body into upper and lower models. The upper body model included the head, thorax, the left and right humerus, radius, and hand. The lower body model consisted of rigid bodies including the pelvis, the left and right femur, tibia, and foot. Joint centers were calculated based on subject specific anthropometric values measured on each subject and consisted of height, weight, shoulder offset, elbow width, wrist width, hand thickness, leg length, knee width, and ankle width. Vicon-Nexus software (Nexus 2.2.1, Vicon, Oxford, UK) allowed for the reconstruction of all thirty-seven markers in a three-dimensional coordinate system. Prior to analyzing any kinematic data, the first step required was to ensure that full contact was made from the foot onto the force plate during collections. Upon playback of a trial, it was imperative to note that no markers of interest were missing. If markers were missing and not accounted for, finding joint angles would be impossible. Therefore if markers were missing, a gap filling method was used to fill in missing markers. Gap fill utilized a marker's known trajectory before and after the missing time period to best predict the anticipated trajectory with a cubic spline function. Once all markers were accounted for, it was essential to recheck that all markers were correctly labeled, as the auto labeling of markers occasionally inverted left and right limbs.

The kinematic marker trajectories and force data were both filtered at 20 Hz using a fourth order Butterworth filter and the kinematic data was interpolated and synchronized to the force data at each time step. Euler joint angular positions as well as velocities, and accelerations were calculated from the filtered 3D marker coordinate data using the flexion-extension, varus-valgus, internal-external rotation (YXZ) sequence which yielded angular conventions defined in the data collection system's coordinate system represented by flexion (+) and extension (-) in the sagittal (X) plane, varu (+) and valgus (-) in the frontal (Y) plane, and internal (+) and external (-) rotation in the transverse (Z) plane from which the (external) ankle, knee and hip joint moments and powers were subsequently calculated using inverse dynamic analyses (Plug-In Gait Marker Set, Vicon, Oxford, UK).

Protocol

With the markers attached, each participant completed 8 punching-CMJ attempts as describe here. The gymnast began on the 30 cm box and then stepped off, immediately using a punching CMJ to leave the ground again before returning back on the force plate. No verbal instruction as to how to execute the movement was provided by the coach other than to state a punch was to be used. The coach assigned the rating efficiency to each trial at the time of the data collection. The coach then re-watched each trial's recording to more precisely rate and assign the trial to its appropriate category. The trials were categorically ranked by an expert gymnastics coach (SCA), who characterized them to one of five categories; bad, poor, acceptable, good, very good. These categories describe the efficiency in terms of their height, speed, stiffness, and control of the body of the athlete, both in rotation around short axis and in spatial coordinates. These are the same subjective criteria observed and judged in competition.

Analysis

The first variable utilized in the analysis was the peak LVGRF occurring during the punch. This yielded information regarding the external force being exerted during the punch trial between the subject and the force plate. The second dependent variable of interest was peak (instantaneous) ankle power. This demonstrated the amount of work ($\mathrm{W}\angle = T * \Theta$) produced at an instantaneous time period ($P = W\angle/\Delta t$), and provides an overall assessment of torque and velocity of the performance at the ankle during the punch.

CHAPTER IV

RESULTS

Not all subjects exhibited an efficiency rating in 1 single category. Individual variances allowed for 19.15 % of all trials to be of bad and poor efficiency, while 42.55 % were labelled as good or very good. Only 1 subject at this level of competition exhibited 90% greater performances in the very good category.

The mean values of each of the categories for LVGRF (Figure 1, Appendix A: Table A-1, raw values; Table A-3, body weights) ranged from a high value of 35.7 N/kg ± 5.4 N/kg to a low value of 26.6 N/kg ± 4.8 N/kg.

The values for peak ankle power show that the values are negative, indicating that it occurs during absorption phase of the punch. Observation of video of the event indicated that the peak is achieved at the end of the eccentric phase, just prior to the subject initiating concentric action to generate energy in order to achieve lift off the plate. The mean values of each of the categories for Lankle power ranged from a high value of -20.170 w/kg ± 19.8 w/kg to a low value of -33.189 w/kg ± 6.462 w/kg (Figure 2, Appendix A: Table A-2).

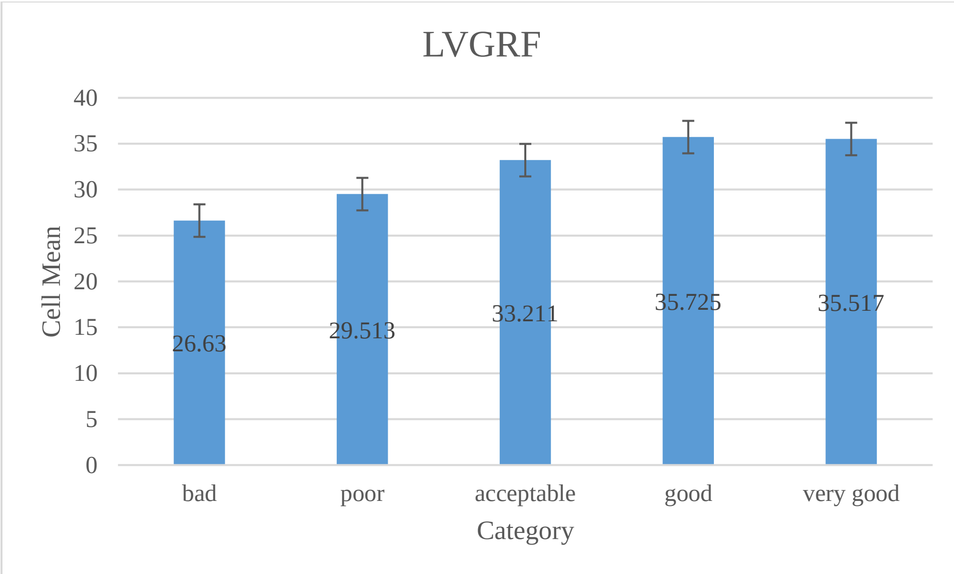

Figure 1. Bar Plot for LVGRF

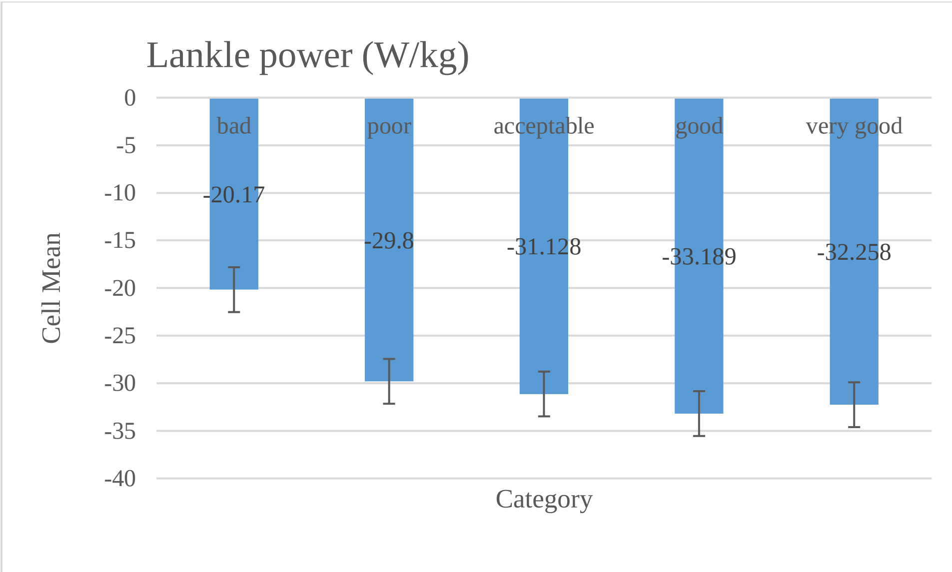

Figure 2. Bar Plot for Lankle Power

CHAPTER V

DISCUSSION, LIMITATIONS AND CONCLUSIONS

In WAG, the goal is to get the optimum amplitude on skills with minimal wasted energy. Pertaining to those skills that are connected by a punching CMJ, this is characterized by time spent in contact with the performing surface, and the perceived efficiency of that punch to the trained eye. A 'softer' style punch (that a trained eye would call inefficient), ends up with lower elements in terms of height from the performing surface most often resulting in deductions from score and possible injury to the performer. A 'more rigid' punch landing could yield higher scores, however these may also predispose the athlete to higher loads and thus injuries. Knowing that coaches are always striving to get a more efficient punch to achieve better height and connection, quantifying the kinetics involved could help the coach to better understand the kinematics that the coach observes and uses to help inform their decisions as to the overall efficiency of a punching CMJ, and the outcomes of that punch in practical application. The LVGRF data shows a clear trend, with values increasing as the efficiency increases. This supports the notion that gymnasts that master this motion will experience exceedingly higher forces then their less skilled counterparts and thus be more prone to injury. Coaches may use this information to grade conditioning/training levels such that more skilled athletes experience less impacts within any training session or season.

In these trials, there is also a trend in the left ankle power, that shows larger values for power in the 'very good' trials, and a downward trend as you go through to the 'bad' trials. The range of the Lankle power values is similar to the values reported in a comparison of soft and stiff landings[9] , with the 'bad' end of the scale corresponding to the 'soft' landings, and the 'very good' end of the scale corresponding to the 'stiff' landings.

We see the same corresponding trend in ground reaction forces, with the stiff landings in drop landing studies [14] having higher peak ground reaction forces than soft landings from the same height. Our more efficient and stiffer punching CMJ showed a similar trend in peak LVGRF when expressed in number of bodyweights. Comparing our peak GRF values to a drop landing of a similar height [11], we note values in the same range with our lower end mean values for our peak LVGRF during the punching CMJ.

When utilizing the criteria an expert coach uses in rating efficiency of movement, kinematic 'noise' is a primary concern. 'Noise" is defined as the amount of extra kinematic motion, that helps describe whether the athlete is in control over her limbs in such a fashion as to transfer as much force through the floor and in the correct angle to achieve the desired end result, be it eventual rotation around short and/or long axis, or simply connection of two jumping elements. Coaches are also observing angles besides the ankle, including hip and knee. Coaches are observing whether or not the athlete needs to use their upper limbs and/or trunk angle in order to control direction of motion and balance.

Kinetic information in this study is clearly linked to efficiency as rated by an expert coach. This opens up many possibilities for the application of that data in daily practice settings in the gym. In a turn-to-turn basis, it allows a coach to get a general sense of how much force the athlete is accumulating over a number of turns. It needs to be noted that more force might not necessarily mean accumulating a higher chance of injury, as a more efficient punch could do less overall damage, due to everything in the lower leg working to absorb and redirect, instead of possibly being out of alignment on a less efficient punch. That is something that could possibly be assessed in a different study.

In a larger sense, as the athlete accumulates turns, looking at a pattern from an individual could be very helpful to a coach in designing a plan for practice on each event. For example, if an athlete consistently shows high efficiency (for example subject seven had seven 'very good' and one 'good' trial over the course of the eight trials she performed) then the coach might consider that subject more masterful in her execution, and needing less turn in the gym to achieve the same result as a subject who had a wider range of rated efficiency (subject nine had trials in all five categories over the course of eight trials in this study). Those subjects with a wider range of efficiency might need more turns, could possibly be at higher risk of injury, or might even need to have the nature of their turns in the gym restructured to perform less complex tasks in order to re-teach correct movement patterns. (it is a common practice to go back to drilling shapes and basic movement in order to get better results or in the teaching of new and more complex movements.

This observation in the data could lead to the coach modifying the practice schedule, if certain movements are deemed more efficient than others, so that the athlete could spend more time on those movements she has not mastered, instead of repeating turn on a skill she has already shown competence with.

This quantification of the kinetics involved in a punching CMJ could also lead to the possible development of screening tools for coaches. It might be possible to 'test' these movement patterns and make guesses as to the possible efficiency in the execution of more complex skills by the athlete, the success rate in completing the execution of practice and competition, and even scoring potential for the athletes. The expert coach in this study has knowledge of the subjects, and anecdotally, there was some correlation between efficiency in these trials and success in competition, particularly on the floor exercise.

This study was purposefully kept simple, as no specific research on the punching CMJ in terms of kinetics has been conducted; nor how these mechanics communicate to a coaches subjective rating of efficiency has been conducted. There are a large amount of variables that could be evaluated and certainly this initial look into it would invite further questions and examination of those variables, but the clear trend in the data in this study shows that it is possible to relate performance with the LVGRF and the Lankle power involved in execution of these trials. That leads to a number of possibilities in the design and implementation of a training plan with collegiate female gymnasts.

While this study gives a glimpse into the possible trends in data behind the decisions that coaches make from turn to turn in the practice gym, there are also limitations in how it might be extrapolated to actual numbers in a full performance setting. The heights and forces involved are small relative to what gymnasts endure in their daily practice and performance situations, so there are some questions as to scalability. Although an expert coach was utilized in the categorizing of the punch jumps, the variability in rating these motions between coaches and even Olympic level judges is pervasive in WAG and would affect these results. By selecting an a priori five-step scale, more variability in categories was achieved to accommodate the wide range of skill sets in the athletes involved. We may have chosen a smaller categorical rating system such as a three-step, but this would not have altered the outcome; and, considering that NCAA and Olympic judging scales are set between 0-10, would have moved our application further from the intended setting. This was a laboratory controlled setting study. Hence, there is also the fact that no short axis rotation or multi planer motions involved. Lastly, through IRB mandate we utilized a 30 cm height that was relatively small [but safe] compared to heights these gymnasts would typically perform. This most likely would serve to increase the variability in the performances and also limited the application of our data to be directly applied to the competitive setting.

In conclusion, this descriptive study has shown that as the efficiency of a punching CMJ increases, the peak LVGRF increases as does the Lankle power in the eccentric phase of the CMJ. These data may be used to help coaches limit impact exposures to those athletes who have mastered the punch jump in order to reduce stresses on their ankle.

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APPENDIX: TABLES

Table A-1. Means Table for peak LVGRF (N/Kg)

Effect: efficiency rating

Category	Count	Mean	Std. Dev.	Std. Err.
Bad	10	26.630	4.828	1.527
Poor	8	29.513	5.829	2.061
Acceptable	36	33.211	4.003	0.667
Good	28	35.725	5.414	1.023
Very good	12	35.517	2.604	0.752

Table A-2. Means Table for Lankle power (W/Kg)

Effect: efficiency rating

Category	Count	Mean	Std. Dev.	Std. Err.
Bad	10	-20.17	19.839	6.274
Poor	8	-29.8	6.463	2.285
Acceptable	36	-31.128	6.579	1.096
Good	28	-33.189	6.762	1.278
Very good	12	-32.258	4.931	1.423

Table A-3. Body Weights Per Category

Category	Mean LVGRF	Approximate number of body weights (BW)
Bad	26.63	2.7
Poor	29.513	3.0
Acceptable	33.211	3.4
Good	35.725	3.6
Very good	35.517	3.6