THE EFFECTS OF CHEERLEADING SURFACES ON LANDING CHARACTERISTICS DURING VERTICAL AND FLIP LANDINGS

by

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ABSTRACT

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Lateral ankle sprains are common injuries in cheerleading and typically occurring during tumbling. The landing surface can impact injury risk by modulating loading parameters and risky joint positions. Most surface-landing studies have used vertical landing tasks to study acrobatic populations, and few studies have compared vertical and flipping tasks. Therefore, the purpose of this study was to compare the effects of two cheerleading surfaces between vertical drop landing and flip landing tasks. Doing so explained surface characteristic influences on landing and the validity of using vertical landing tasks to represent acrobatic sports. Twelve collegiate cheerleaders (7 females, 5 males; age: 21.0 ± 2.5 years; mass: 64.5 ± 14.5 kg; height: 1.7 ± 0.1 m) performed flip (FLIP) and vertical (VERT) landing tasks over a harder (HARD) and matted (MAT) surface. Three-dimensional kinematics and kinetics were collected, and sagittal and frontal plane kinematic and kinetic variables were extracted during landing. Repeated measures ANOVAs (task x surface) were conducted to determine task and surface effects ($p < .05$). The FLIP task caused significantly greater impact peaks and loading rates, greater knee flexion at IC, peak knee extension and abduction moments, greater ankle plantar flexion and eversion moments, and less ankle plantar flexion at IC. There was greater vertical foot velocity at IC during FLIP tasks which was primarily due to angular velocity, and it likely explains the greater loading characteristics during FLIP tasks. The HARD surface landing caused significantly greater loading rates, greater knee flexion and ankle inversion at IC. Sagittal ankle moments had a significant task and surface interaction ($p = .006$), but no joint moment surface effects were observed. These indicated that FLIP and VERT tasks are significantly different due to angular components. The larger forces and joint stress observed in flipping places individuals at greater risk for ankle injuries. Flipping on a harder surface also introduced higher risks. The theory that landing on harder surfaces increases injury risk is supported. These results also caution individuals when generalizing vertical landings to acrobatic populations.

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Chapter 1: Introduction

Cheerleading is a relatively new and fast-growing sport. With the International Olympic Committee's recognition of cheerleading as an Olympic sport, it will only gain more traction and popularity. This acrobatic sport has been linked to numerous injuries, as with any sport that involves impacts. Although football has one of the highest records of overall injuries, cheerleading was found to have the highest records of injuries that caused longer periods of time off (Bagnulo, 2012; Currie et al., 2016). Of all the injuries in cheerleading, sprains and strains are the most prevalent (52%), and the ankle is the most common site for these injuries (68%) (Shields and Smith 2011). Sports like basketball, volleyball, and soccer also show similarly higher occurrences of ankle sprains (Lempke et al., 2021; Morris et al., 2021; Baugh et al., 2017; DiSefano et al., 2018). As a result, lateral ankle sprains are a major cause of time off from participation in various sports, including cheerleading. With the inclusion of cheerleading as an Olympic event, the athlete base may see a rise in number as popularity grows, and so may the numbers in ankle injuries.

Risk factors for ankle sprains can be separated into intrinsic and extrinsic factors. Non-modifiable intrinsic risk factors can include gender, anthropometric variables, and a history of ankle sprains (Doherty et al., 2014; Delahunt and Remus, 2019; Gross and Liu, 2003; Boden et al., 2003). Modifiable intrinsic risk factors can include strength imbalances and balance and proprioception deficits (Kobayashi et al., 2016; Trojian and McKeag, 2006; Payne et al., 1997). Extrinsic factors can include the setting, type, and position within a sport, the foot position before and at foot contact, the performance surface, and the type of shoes and/or orthosis worn in sport (Doherty et al., 2014; Whiting and Zernicke, 2008, p. 195; Tropp et al., 1985, McKay et al., 2001; McNitt-Gray, 1993).

Cheerleading and gymnastics share many similar characteristics with each other. For example, both sports involve tumbling, high jumping, aesthetic components, and routine-based performances. And because both sports share similar activities, the injury risks in both sports are comparable. Cheerleaders, gymnasts, and other acrobatic athletes have all been observed to have a high risk of ankle injuries (Marshall et al., 2007; Grapton et al., 2013). The majority of ankle sprains occur during the landing phases of tumbling and stunts in cheerleading and during the floor exercise in gymnastics (Shields and Smith, 2011; Marshall et al., 2007). Despite the similar injury trends, there are key differences between the sports that can alter the injury parameters. Cheerleaders are known to perform on hardwood floors and padded surfaces, and gymnasts perform on spring floors. Cheerleaders are also unique from gymnasts because they perform and tumble in shoes while gymnasts perform barefoot. The different surfaces and footwear of the two sports can alter impact characteristics, which can then alter their injury risks (McNitt-Gray et al., 1993; Niggs et al., 1987).

Sports involving jumping and landing generally have elevated injury risks, and modulating high impact forces during landing can have great effects on those risks (Herzog et al., 2019; Gulbrandsen et al., 2019; Baugh et al., 2017). Jumping/landing can be observed in activities like tumbling in cheerleading and gymnastics, making jump shots in basketball, launching for a head-butt in soccer, or spiking in volleyball. During landing, an impact force is the external ground reaction force generated from ground contact. High impact forces and the rates at which these are reached (loading rates) from landing have been associated with increased injury risk (Barrett et al., 1998; Radin and Paul, 1971; Schwellnus et al., 1990). The literature suggests the surface, the type of show worn, and the technique of landing can have an effect on impact forces and joint loading (Malisoux et al., 2017; Wei et al., 2018; McNitt-Gray et al., 1993; Laughlin et al., 2011). Shoes and landing surfaces/mats with greater cushioning and compliant properties and materials have been shown to attenuate high impact forces (McNitt-Gray et al., 1993; Malisoux et al., 2017; Wei et al., 2018). Reductions in impact forces would lead to lower injury risks. Malisoux and colleagues (2017) reported harsher impact parameters when landing on a hard surface as opposed to landing on a cushioned surface. McNitt-Gray and colleagues (1994) found lower impact peaks but larger joint compensations when landing without a cushioning mat. Since collegiate cheerleaders are known to perform on both hardwood and padded surfaces, these findings would suggest increased injury risk when performing on hardwood. Although shoes and surfaces both effect injury risk parameters, cheerleading surfaces likely have greater influence because cheerleading mats and landing pads tend to be thicker and have more cushioning material than a shoe's midsole. Therefore, examining the effects of specific cheerleading surfaces is important in understanding the sport's injury risks.

Most of what is known about impact force modulation has derived from vertical landing studies. Simple vertical landing tasks, like drop landing or vertical jump landing, are the most common in these studies. These tasks may better reflect sports like volleyball, soccer, and basketball, where jumps occur more straight up and down. Even between various vertical landing methods (e.g., drop landing, jump landing, drop-jump landing, etc.), studies have reported dissimilarities in sagittal and frontal plane kinematics, kinetics, and muscular responses (Afifi and Hinrichs, 2012; Edwards et al., 2009; Harty et al., 2011). Although there are parallel actions between vertical landing tasks and actual performance in jumping sports, there are apparent differences in landing dynamics between simple tasks and real-life tasks. The range of dissimilarity may only continue to grow if the tasks themselves are not purely vertical jumping/landing. Therefore, it is questionable if this simple landing model reflects performance in gymnastics or cheerleading. Flip landing in acrobatic athletes may differentiate from the standard landing paradigm in terms of achievable flight heights and the angular momentum generated.

Tumbling flight heights are observed to reach greater vertical heights than regular vertical jumps. Knoll (1996) reported flight heights of 1.72 m while performing a round-off, back handspring, double back tuck. This height is substantially different than "good" vertical jumpers that can only reach average heights of 0.56 m (Vanezis and Lees, 2005). The addition of back handsprings in tumbling enables reaching greater flight heights as compared to a vertical jump. These discrepancies are also reflected in gymnastics landing papers that use drop landing heights from 0.69 to 1.82 m (McNitt-Gray et al., 1993; McNitt-Gray et al., 1994), whereas other vertical landing papers used drop heights around 0.3 to 0.6 m (Fong et al., 2011; Wei et al., 2018; Wang et al., 2017). These studies demonstrate substantially greater impact loading characteristics as compared to studies using lower drop heights.

Simple vertical landing tasks may also not be relatable to flipping due to the special rotational dynamics. Flips differ from regular jumps because there is an added angular rotation component, and they can become even more complex when twists are added. Drop landing tasks only involve dropping straight down. Projectile objects with angular momentum can only stop rotating once an external torque acts upon the object (e.g., ground reaction forces). Gymnasts and cheerleaders typically land from a flip, tumbling pass, or routine dismount. Rarely do these athletes jump and land strictly vertically. As a result, these athletes likely land with considerable amounts of velocity and in a non-vertical orientation. The few studies that have compared vertical landing tasks to flip landing have found discrepancies in landing kinematics (Beatty et al., 2007; Comfort et al., 2016). Therefore, the angular motion of flipping may also influence impact parameters, but no studies have directly compared kinetics between vertical and flip landings.

The use of flip landing protocols is seldom mentioned in the landing literature. However, the studies that did utilize flip landing tasks may be more representative of real acrobatic landing. Xiao and colleagues (2017) used tumbling kinematics from a single subject to perform computer simulations of landing on mats of different stiffness. Similarly, Wu and colleagues (2019) used single-subject computer simulations to examine landing responses and control of a backflip. These papers are distinctive from other landing papers because they were the only studies that collected actual tumbling data to examine potential kinetic and muscular responses. Because of this, the simulated muscular responses, landing kinematics, and landing kinetics they reported may be more accurate responses in cheerleaders and gymnasts compared to the responses from vertical landing. These studies also focused on sagittal plane mechanics, while risk factors for injuries such as ankle sprains include non-sagittal plane loading characteristics. Also, these studies were limited due to the fact they were single-subject designs that provided baseline data for computer simulations. The studies also did not compare their results to vertical landing data. Therefore, it still remains unclear how the angular motions of flipping affect landing impact characteristics between simple vertical landings and flip landings and how surface interactions may affect landing behavior. Overall, flip landing mechanics may be unique from drop/jump landing mechanics, and the use of drop landing protocols to summarize landing from acrobatic maneuvers may not be entirely practical or accurate. Testing the parameters of how these tasks differ may provide more insight on the generalizability of simple landing tasks in the acrobatic population and how angular motion at landing influences impact characteristics.

Statement of Purpose

The purpose of this study was to compare the effects of two cheerleading surfaces (hard vs. matted) between vertical drop landing and flip landing tasks. Doing so helped determine the influence of surface characteristics on landing mechanics and the ecological validity of using simple vertical landing tasks to understand impact and injury risk modulation within the sport of cheerleading.

Hypotheses

1. The impact peak and loading rate will be greater when landing on the hard surface and when landing from the flip task. The two tasks will respond similarly to the change in surfaces.
2.
    a) Sagittal plane touchdown angles and ROM at the knee and ankle will be greater when landing on the hard surface and when landing from the flip task. The two tasks will respond similarly to the change in surfaces.
    b) Frontal plane touchdown angles and ROM at the knee and ankle will be greater when landing on the hard surface and when landing from the flip task. The two tasks will respond similarly to the change in surfaces.
3.
    a) Peak sagittal plane knee extension and ankle plantar flexion moments will be greater when landing on the hard surface and when landing from the flip task. The two tasks will respond similarly to the change in surfaces.

b) Peak frontal plane knee abduction and ankle eversion moments will be greater when landing on the hard surface and when landing from the flip task (Ueno et al., 2020). The two tasks will respond similarly to the change in surfaces.

Delimitations of the Study

1. Recruited participants were collegiate-level cheerleaders.
2. Participants must have had at least one year of prior cheerleading experience and active with a collegiate team within the last six months
3. Participants could not participate in the study if there is an existing condition(s) that interferes/prevents normal execution of the study’s activities.
4. Participants could not be pregnant.
5. Participants must have shown video proof of their ability to adequately perform the study’s flipping task.

Assumptions of the Study

1. All lower-extremity segments were rigid bodies.
2. All equipment was calibrated appropriately before each testing session.
3. All retro-reflective markers were placed accurately on the appropriate anatomical landmarks.
4. Participants were flipping as they normally would during practice or competition.
5. While there are likely individual asymmetries, the right leg should be representative of bilateral landing mechanics across the population.
6. The approximation of the center of mass (COM) displacement during the drop landing task was similar to the flip task COM height.

7. Participants recruited from local, midwestern universities reflected the landing of other collegiate cheerleaders.

Significance of the Study

Investigating the potential differences between flip landing and drop landing helped explain the validity of using simple landing tasks to study the gymnastic/acrobatic population. Next, investigating the effects of landing surfaces helped explain how impact forces are modulated within cheerleading. As of now, this may potentially be the first known study to test the landing effects of cheerleading surfaces and to collect multi-subject flip landing kinetics. The results of this study may also guide the methods of future landing studies and surface interfacing decisions within this particular population. Lastly, this study will add to the small body of scientific literature on the young sport of cheerleading when future publication is achieved.

Chapter 2: Literature Review

Introduction

Although the National Collegiate Athletics Association (NCAA) does not yet recognize cheerleading as a sport, the International Olympic Committee (IOC) fully accepted cheerleading as a sport on July 20, 2021. The American-born sport increases in participation by roughly 18% each year, and with the inclusion of cheerleading as an Olympic event, the numbers may only grow more from there (Bagnulo, 2012). The origins of cheerleading and pep-squads all started at the University of Minnesota in 1898 when Johnny Campbell led the home-team audience through the first organized crowd chant. Back then, that was all it was: chanting, cheering, and raising energy and spirits. The cheerleading that we know and have grown accustomed to today is much more involved and complicated than what originated. As the general sport still contains the spirit-raising aspects, it is now a mixture of other components, like acrobatics and gymnastics. The acrobatic skills can consist of stunts/pyramids where a base(s) holds a flyer in the air or baskets where bases launch a flyer to perform airborne skills (Table 1). Then, the gymnastics skills can consist of particular body positions, jumps, and tumbling. Present-day cheerleading requires not only an energetic attitude but also skill, athleticism, and stamina (Boden et al., 2003). Unlike other sports, cheerleading is a year-round ordeal with games, competitions, preparation practices, summer training camps, and pre-summer training camp practices.

Table 1. A list of cheerleading terms and their definitions.

	Cheerleading Terms
Term	**Definition/Description**
Backspot	The individual standing behind a group stunt and assisting the main side base.
Base	An athlete that holds/tosses a flyer in the air with their hands.
Basket	A maneuver involving 4 bases tossing a flyer in the air to perform aerial skills. The flyer then descends on their back into the bases arms in a cradle-like catch.
Flyer	An athlete that is held/tossed in the air by a base(s).
Main-Base	The primary base of a group stunt (see base).
Pyramid	A stunt involving multiple bases and flyers to form a human structure. Pyramids can be 2 people high in high school and All-Star cheerleading, or 2.5 people high in college and All-Star cheerleading.
Running Tumbling	A series of flipping skills that involves a running start and typically involves a round off after the running phase (unless the individual is flipping forwards).
Side-Base	The base that assists the main base in a group stunt (see base).
Standing Tumbling	Flipping skills that do not involve a running start and typically do not involve a round off. Standing tumbling skills can be singular skills (e.g. A single standing back tuck), or a series of connected skills (e.g. Two connected back handsprings).
Stunt	A skill involving 1-4 bases holding a flyer in the air with their hands. Bases will not release the flyer out of their hands until a dismount is executed.

Since the sport has transitioned from purely chants to routines filled with high flying and flips, injuries accompanying that transition are only expected. Studies found cheerleading to have an injury rate of .71-2.8 per 1000 athlete-exposures (AEs) compared to the highest finding of 12.53 AEs in football (Bagnulo, 2012; Currie et al., 2016). However, the same studies also reported cheerleading as having the highest amount of injuries that cause sustained time-out (3 weeks or more). This would indicate that although cheerleading had the lowest recorded injuries, it had the highest number of critical or more severe injuries. Injury occurrences have increased by 110% from 1990 to 2002, with the average cheerleader acquiring 3.5 injuries in their career (Shields and Smith, 2006). But, that rate may be much higher today with the increased demands and advancement of skills (Jacobson et al., 2004; Jacobson et al., 2005). Those numbers may also be much higher than we think since cheerleading is not an NCAA sport, and there is no governing body that requires the reporting of all cheerleading injuries (Boden et al., 2003).

As stated previously, cheerleading is typically a year-round sport between cheering at games and prepping for competitions. Individuals who participate in year-round sports have elevated overuse injury risks compared to individuals who take breaks in-between sports seasons (Cuff et al., 2010). Other than occurring year-round, the sport is also unique because the athletes are known to perform on various surfaces. Cheerleaders may perform on turf, grass, and/or vinyl/hardwood basketball surfaces when cheering at games and typically on a foam mat during practices and competitions. One study found that 68.8% of injuries occurred on practice mats, 11.6% occurred on vinyl/hardwood floors, and 8.4% on football sidelines (Currie et al., 2016). Although most injuries happened on a matted surface, practicing or performing on grass, turf, vinyl, hardwood, or wet surface may increase the risk of sustaining a severe injury (Boden et al., 2003; Waters, 2012; Shields and Smith, 2009a; Shields and Smith, 2009b). The same study also found no significant difference in injury rates between practices and competitions. However, another study found more injuries occurred during practices than competition or sporting events (Shields and Smith, 2009a). Most injuries happened during tumbling and stunting activities (Shields and Smith, 2006). Although, basket tosses and pyramid activities place cheerleaders more at risk of severe injuries due to falls from high heights (Shields and Smith, 2009a; Shields and Smith, 2009b). Females also have the highest injury rates in cheerleading compared to males

(Boden et al., 2003). Although, that observation might be more attributed to cheerleading being a female-dominant sport, and females are typically the flyers at the top of a stunt or toss and are more likely to sustain critical fall injuries.

Common Injuries

Of all cheerleading injuries, the most injuries occurred in the lower extremity (37.2%), followed by the upper extremity (26.4%), and then the neck (18.8%) (Shields and Smith, 2011). Sprains and strains made up the majority of those injuries (52%), followed by fractures and dislocations (16.4%) and concussions (3.5%). Sprains and strains were most prevalent at lower extremity sites (42%) (Shields and Smith, 2011). These injuries also occurred in the upper extremities, trunk, and neck, but they appeared the most in the lower extremities. Most lower extremity sprains/strains occurred at the ankles (68%) followed by the knees (22%) (Shields and Smith, 2011). Therefore, ankle sprain/strain injuries are the most prominent injury in the realm of cheerleading.

The cheerleading activities displaying the highest rate of ankle sprain/strain injuries are running tumbling, which features a running start (78%) (Shields and Smith, 2011). This is followed by stunts and pyramids (74%), standing tumbling (tumbling without a running start) (71%), and jumps (60%). In terms of the specific branches of cheer, college cheering had the highest rate of ankle sprains, followed by high school cheerleading, then All-Star cheerleading (Shields and Smith, 2011). All-Star cheerleaders were more likely to acquire an ankle sprain while tumbling, whereas high school cheerleaders were more likely to sustain one from stunting. Ankle sprains were also most common during practice compared to competition across all branches. Time-off from participation seemed to be lower in college cheerleading than All-Star or high school cheerleading (Shields and Smith, 2011). One study found that high-level gymnasts were more likely to participate despite an injury than their lower-level counterparts (Kolt and Kirby, 1999). With that in mind, collegiate cheerleaders having shorter time-off from participation could be taken in two ways: either ankle sprains in college cheerleading tend to be less severe, or college cheerleaders are more likely to participate through an ankle injury.

Other sports also feature comparable ankle injury risks. Similar to cheerleading, lower extremity ankle sprain and knee derangement injuries are most common in women's gymnastics (69-52%) (Marshall et al., 2007). Those injuries are followed by upper extremity injuries (11-17.8%), then head and neck injuries (5-6.7%). The floor exercise event has the highest rate of overall injury and ankle sprain occurrences (Marshall et al., 2007). Lateral ankle sprains were the most commonly reported injury in collegiate basketball (Lempke et al., 2021; Morris et al., 2021). That was true for both men (16% of all recorded injuries) and women (14% off all injuries) of the NCAA. However, anterior cruciate ligament (ACL) injuries were also notable in women's basketball (Lempke et al., 2021). Ankle sprains in basketball occurred most during games as opposed to practices (71%) and upon landing from jumps during general play (45%) (Herzog et al., 2019; McKay et al., 2001; Morris et al., 2021). In soccer, ankle sprains were the most common injury in high school athletes and were second to upper-leg injuries in NCAA athletes (DiSefano et al., 2018). Gulbrandsen and colleagues (2019) found ankle sprain rates were three-folds higher at games than practices, especially during the second half of a game. This may indicate fatigue may play a role in ankle sprains within soccer. They also found non-contact mechanisms were the most common culprits in soccer (44.9%), like landing from a jump. In NCAA Volleyball, ankle sprains were not only one of the most prevalent injuries but also the most significant cause of time-off from participation in men and women teams (25.3% and 24.3%, respectively) (Baugh et al., 2017). The injury was most common during spiking in competition. Injury rates are higher in men's volleyball compared to women. This may be attributed to higher jump heights achieved by male athletes (Baugh et al., 2017). The various sports mentioned above can be linked to cheerleading because of the comparable prevalence of ankle sprain injury and the similar tumbling or jumping/landing elements within each sport. Since cheerleading as an organized sport is relatively new, the literature of other jumping/landing sports may provide crucial insight in understanding injury risk in cheerleading.

Mechanism of Injury

Lateral ankle sprains are the most common type of ankle injury, making up 85% of all ankle sprains (Whiting and Zernicke, 2008, p. 195). These injuries occur when the ankle joint's lateral ligament structures (anterior talofibular, posterior talofibular, calcaneofibular ligament) are suddenly overstretched. Mechanisms of a lateral ankle sprain involve a mix and match of ankle plantar flexion, inversion, and internal rotation of the foot; these mechanisms can occur when individuals step wrongly on an uneven surface or object, quickly change walking/running direction, or during landing movements (Whiting and Zernicke, 2008, p. 195). It is suggested the lateral structures have a sequential order of failure. The anterior talofibular ligament is the first to fail during these mechanisms, then the calcaneofibular ligament, and then the posterior talofibular ligament (Whiting and Zernicke, 2008, p. 196; Siegler et al. 1988). However, most lateral ankle sprains only involve the anterior talofibular ligament, and few are severe enough to include injury to the posterior talofibular ligament.

Ankle sprains are also classified as medial ankle sprains and high ankle sprains. A medial ankle sprain is the exact opposite of a lateral sprain, where an eversion movement at the ankle occurs. The deltoid ligament is the medial structure is the primary damaged structure. Mechanism of this injury includes eversion during dorsiflexion and external rotation of the foot

(Whiting and Zernicke, 2008, p. 197). This type of mechanism is most common during contact with other players in sports (Clanton et al., 2020). High ankle sprains involve injury to the interosseous membrane and tibiofibular ligament (the syndesmosis). Mechanism for a high ankle sprain includes talar torsion and dorsiflexion (Whiting and Zernicke, 2008, p. 197). These mechanisms mainly occur when the leg externally rotates relative to a fixed foot (Clanton et al., 2020). As a result, the fibula separates from the tibia, and the syndesmosis is damaged (Whiting and Zernicke, 2008, p. 197). Football, hockey, and soccer have the highest recorded occurrences of high ankle sprains (Mauntel et al., 2017). High ankle sprains also occur more frequently than medial ankle sprains because the lateral malleolus of the fibula typically prevents excessive eversion (Waterman et al., 2011; Clanton et al., 2020). Lateral malleolus fractures may accompany the rare medial sprain (Whiting and Zernicke, 2008, p. 197). But in general, medial and high ankle sprains as a collective whole only account for a meager 10-15% of all ankle sprains, and lateral ankle sprains are most likely to occur in jumping sports compared to the other two types (Whiting and Zernicke, 2008, p. 197; Waterman et al., 2011).

Risk Factors

Intrinsic Factors. Risk factors for ankle sprain injuries can be separated into intrinsic and extrinsic factors. Intrinsic factors are the variables found within and are specific to an individual. One systematic review concluded that children younger than the age of 12, as opposed to adults or teens, have a greater risk of ankle sprain (Doherty et al., 2014). In addition, another review by Fong and colleagues (2009) found that ankle sprains were the most commonly occurring injury in college athletes. These two observations may imply that children are most at risk for ankle injury as a collective whole. Still, college athletes are more likely to sustain an ankle injury over other injuries. The influence of gender as an intrinsic risk factor is still inconclusive thus far.

Doherty and colleagues (2014) found females have a greater risk of ankle sprains than males. Similarly, a study featuring enlisted individuals found female officers have a higher risk of ankle sprains than male officers (Fraser, 2021). Despite these studies, other studies did not find significant relationships with gender and ankle sprains (Fong et al., 2009; Delahunt and Remus, 2019). The relationship between anthropometric variables and ankle sprain risk is also not fully agreed upon between studies, but it seems the general consensus does lean towards one way. Most studies agree that a relationship exists between body mass index (BMI), body mass, and ankle sprain risk (Delahunt and Remus, 2019; Fousekis, 2012; Kobayashi et al., 2016). Individuals with a higher-than-normal BMI or overweight individuals display higher risks of ankle injuries. Fong and colleagues (2009) also found that a wider foot size may contribute to a higher risk of injury. One study found no significant relationships between height, body mass, or BMI on ankle sprain risk (Willem et al., 2005). But despite those findings, it seems the general literature indicates a relationship between anthropometric variables and ankle injury risk.

An intrinsic factor described as one of the most important predictors of ankle sprain injury is a previous history of ankle sprains (Gross and Liu, 2003). Fong et al. (2009) and Delahunt and Remus (2019) agree that having a history of an ankle sprain places an individual at higher risk of a reoccurrence. A study with recreationally-active college students supported their conclusions and found students with a past history of sprains were twice as likely to suffer from another sprain (de Noronha et al., 2013). Although a bit more dramatized, another study featuring basketball players found athletes with a history of sprains were five times more likely to re-experience the injury (McKay et al., 2001). Athletes may often not take the appropriate time to heal and recover, and many may resume participation at the next practice or scheduled event (Swenson et al., 2013). This ill-advised behavior pattern can result in reoccurring or worsening of an injury. Within cheerleading, ankle injuries were found to be the most recurrent injury and can account for 10-16% of all injuries (Shield and Smith, 2011). Often, the recurrent episode can lead to more devastating consequences than the previous episodes (Shield and Smith, 2011; Swenson et al., 2013). Related to recurrent injury, pain has been linked to long-term recovery outcomes (O'Connor et al, 2013). Pain after an ankle injury may deter individuals from rehabilitation exercises and retraining of the joint. If the joint doesn't not heal properly and remains weakened, individuals will be more likely to experience reinjury (Admad et al., 2020).

Not all studies have come to the same conclusion on sprain history, however. One review found previous history of the injury as a risk factor to be inconclusive (Beynnon et al., 2002). Another study with soccer players found ankle sprain history not to be a significant predictor of future injury (Fousekis, 2012). Altogether, some articles in the literature find a history of ankle sprains to be an inclusive predictor of future sprains. Still, it seems the general literature considers it as a profound risk factor.

The risk factors mentioned thus far are not considered modifiable. Body mass can somewhat be considered modifiable through training or dieting. However, the Set-Point Theory would suggest an individual's body favors a particular body composition in specific environments (Harris, 1990). The following intrinsic risk factors are considered more modifiable than the others previously mentioned. These intrinsic factors are addressed through intervention and training with time. One potential modifiable risk factor would be ankle range of motion (ROM). Self-stretching and myofasical release techniques can effectively increase ankle ROM (Jeon et al., 2015; Stanek et al., 2018). De Noronha and colleagues (2006) concluded deficits in dorsiflexion ROM is a risk factor for ankle sprains. However, that was the only paper in this literature review to come to that conclusion, and all other have found no significant influence

(Beynnon et al., 2002; Fong et al., 2009; Kobayashi et al., 2016). As of now, it is still unclear if decreased dorsiflexion ROM is a risk factor.

Another proposed modifiable risk factor in the literature is muscular strength at the ankle. Deficits or imbalances in muscular strength have been linked to increased injury risk (Kobayashi et al., 2016; Delahunt and Remus, 2019). A study by Baumhauer and colleges (1995) found a high ratio of peak plantar flexion to dorsiflexion torque production was associated with a higher risk of ankle injuries. The same study also found that a higher ratio of peak inversion to eversion torque productions was indicative of greater risk. Adding to their results, the study with soccer players by Fousekis and colleagues (2012) found asymmetries in eccentric strength were significant risk factors. Conversely, de Noronha et al. (2006) reported no significant influence of voluntary strength on injury risk. Willems et al. (2005) also found no difference in plantar-flexion-to-dorsiflexion and inversion-to-eversion strength in females that acquired an ankle sprain versus those that did not. Therefore, it may be possible that muscular strength is a risk factor, even though some studies remain inconclusive.

The next modifiable intrinsic factor mentioned in the literature is balance. A study featuring fall-sport athletes found a positive single-leg balance test (SLB) was a significant predictor of ankle sprain (Trojian and McKeag, 2006). They also suggested the SLB test is a valid tool for assessing ankle injury risk. Alongside those results, a study featuring elite basketball and football players found a significant association between a positive SLB test and acute ankle sprain, but not in recurrent ankle sprains (Halabchi et al., 2016). They also used another balance test in the protocol (star excursions balance test, or SEBT), but only the SLB test had a significant link. However, de Noronha and colleagues (2013) showed a significant relationship between a poor SEBT and ankle sprain in recreationally active college students.

Another study with soccer players found that athletes with a history of ankle sprains had significantly greater postural sway (Tropp et al., 1984). In opposition to the other studies, Vries and colleagues (2010) found no difference in balance between individuals with recurrent ankle sprains, acute ankle sprains, or healthy individuals. But overall, the general literature indicates a significant relationship between balance deficits and ankle injury risk.

The last of the modifiable intrinsic factors is proprioception of the ankle joint. Many articles suggest the main determinate of an ankle sprain (especially a lateral sprain) is the position of the foot before and at external contact (Wright et al., 2000). If the individual's foot is improperly positioned (plantar flexed, inverted, internally rotated) and they are unable to sense the position to correct it, they are more at risk for the mechanisms of injury to occur (sudden and extreme plantar flexion, inversion, and internal rotation). Fousekis and colleagues (2012) did not find a relationship between proprioception and ankle sprain occurrences in soccer players. However, a study with college-level basketball players found proprioception deficits increased the risk of ankle injuries in those players (Payne et al., 1997). Specifically, passive ankle inversion sense deficits were found to increase ankle sprain risk (Willems et al., 2005). This finding would make logical sense because it relates to improper foot placement before/at external contact and the mechanism of injury. Worser scores in proprioception tests were also highly correlated in individuals who scored worse in functional ankle instability (FAI), and having ankle instability has been linked to an increased risk of ankle sprain (Han et al., 2021; Tropp et al., 1984). Proprioception training was shown to effectively improve functional ankle stability and foot position awareness in speed skaters, and it may be a crucial intervention for individuals who experience recurrent ankle sprains or are at higher risk of injury (Winter et al., 2015). In all, it is most probable that diminished proprioception is a modifiable intrinsic risk factor of ankle sprain.

Extrinsic Factors. Opposite to the intrinsic factor, extrinsic factors exist outside of the individual. But even though the following factors are external to the person, they still affect the ankle injury risks. First, and the broadest of them, the type of sport played can profoundly impact an individual's risk of ankle injuries. Beynnon and colleagues (2005) found the risk for ankle injury was highly related to the sport played. However, the that relationship was only observed in females and not in men. Doherty and colleagues (2014) found that indoor, court sports had the highest occurrence and risk of ankle injury. In the NCAA, men's and women's basketball and volleyball had the highest risk of ankle sprains, and those are indeed indoor court sports (Roos et al., 2017). Although, outdoor sports like rugby, soccer, and handball also had noticeably high occurrences of ankle sprains (Fong et al., 2007). Other than the type of sport, the particular position within a sport has an impact on injury risk as well. Defenders and strikers in soccer have significantly higher ankle sprain rates than the other positions (Faude et al., 2006). Then, individuals playing in the front row around the net in volleyball also showed higher rates than the other spots (Eerkes, 2012). It is essential to point out front row players are the only ones legally allowed to spike during competition, and spiking is an action that involves jumping and landing. Enlisted individuals outside of the sports context also showed their roles and specialties impacted their risk of ankle sprains. Individuals in the Infantry, or the individuals who travel by foot, had a higher risk of ankle sprains than the individuals who operated military vehicles (Frazer et al., 2021). Infantry individuals are required to tread rough and unpredictable terrains are placed at higher risk for an inciting event. In contrast, the positions within basketball did not show any relation to ankle injury risk (McKay et al., 2001). Then as an overall observation of athletes, younger athletes who specialized in a single sport earlier on in life were more susceptible of lower extremity injury than those who didn’t (McGuine et al., 2017).

Stated before, the main determinate of an ankle sprain is the foot position before at and at initial contact. Therefore, the foot and joint position at the onset of the exciting event can be considered a significant risk factor (Whiting and Zernicke, 2008, p. 195). Wright and colleagues (2000) noted that increased plantar flexion at touchdown may increase the risk of an ankle sprain. Along with that, kinematic analysis of lateral sprains occurring during tennis matches found increased ankle inversion present at initial contact in all cases (Fong et al., 2012). Another analysis of lateral sprain cases in the high jump and field hockey event at the 2008 Olympics also found ankle inversion present at initial contact (Mok et al., 2011). Then, an analysis of a single National Football League (NFL) medial ankle sprain case found eversion and external rotation present at initial contact (Wade et al., 2018). Therefore, increased plantar flexion and ankle inversion before and at initial contact will increase the risk of a lateral ankle sprain. Then, increased ankle eversion and external foot rotation will increase the risk of a medial ankle sprain. An inverted foot position at initial contact is likely to transition into deeper inversion upon further weight-bearing as peak inversion occurs shortly after initial contact (Tropp, 2002; Delahunt and Remus, 2019). All of which would be a recipe for a lateral ankle injury.

Improper foot placement can be reduced through proprioceptive training and increasing awareness of ankle and foot position or by using foot orthosis. The use of an ankle brace can also help correct ankle and foot position (Eils and Rosenbaum, 2003). Foot position correction is achieved by the brace applying external torque around the subtalar and talocrural joint to resist excessive inversion and plantar flexion before and at initial contact (Tropp, 2002; Fong et al., 2009). A similar effect can be achieved by using the alternative of athletic tape to secure the ankle (Beynnon et al., 2002). One study showed that using two types of orthosis reduced the cases of ankle sprains in soccer players (Tropp et al., 1985). Another study also found similar results where using an ankle orthosis significantly reduced the reoccurrences of ankle sprains in soccer players by five-folds compared to those who did not use an ankle orthosis (Surve et al., 1994). A secondary benefit to using a brace is the potential mitigation of diminished proprioception within individuals with ankle instability or acute ankle sprain (Tropp, 2002). This is achieved by the brace providing somatosensory cues that can increase awareness of the ankle joint and foot position.

Continuing the topic of equipment, the type of shoe worn can also influence the ankle injury risk. A NASA engineer in the ‘70s introduced the concept of placing air cells in shoe heels (Nike, 2019). The famous Nike Air Max, the product of the concept, quickly gained traction and became a booming fad. The idea was that the air cells embedded in the show would soft and cushion impacts in running and jumping. However, there was another effect of the design. McKay and colleagues (2001) found basketball players that wore shoes with air cells increased their risk of ankle sprains by fourfold. Additionally, shoes with extreme traction increase lower extremity injury risk (Wannop et al., 2010; Villwock et al., 2009). Although traction with the playing surface is important in sports like soccer, football, and tennis, too much traction in a shoe design may threaten ankle joint health. Another conception behind a shoe’s design is that a high-top shoe protects against ankle sprains, similar to how an ankle brace or taping provides resistance against risky foot position. However, Barrett and colleagues (1993) found no such reduction in ankle sprain risk in high-top basketball shoes compared to low-top basketball shoes. The same conception exists within cheerleading with the introduction of high-top and low-top cheer shoes. High-top cheer shoes are often marketed for their ankle-protecting properties and tend to be much pricier than their low-top counterparts. Evidently, these athletes may be paying the extra “fad-tax” without receiving the promised benefit. External to sports, a study with the Israeli military found no effect on ankle injury risk based on the type of shoe they trained in (basketball shoes vs. light-weight boots) (Milgrom et al., 1991). It seems as though some shoe choices profoundly impact injury risk while others may not. Either way, athletes should carefully consider footwear to reduce injury risk.

A significant portion of ankle sprains occurs during tumbling in cheerleading and gymnastics, landing from jumps in basketball, and landing from spikes in volleyball. An impact force is the external ground reaction force generated from ground contact during landing. Then, the loading rate is the rate at which the peak impact force is reached. Impact forces from landing can reach magnitudes up to 3-9 times an individual’s body weight (McNitt-Gray, 1993; McClay, 1994). Successful execution of complex skills in sports like cheerleading and gymnastics can call for increases in flight height that will result in greater impact forces (Mills, 2010). It’s reported female gymnasts land from heights greater than 1.5 m, but cheerleaders may fall close behind if they are not performing on a spring floor (McNitt-Gray et al., 1993). So, it’s possible cheerleaders may reach impact peaks up towards nine times their body weight and above. The risk and severity of an ankle sprain can be determined by the magnitude and rate of external forces acting on the joint (Whiting and Zernicke, 2008, p. 195). In terms of foot contact with the ground during landing activities, the impact force is the external force to blame. Ankle sprain injuries occur as these impact forces are transferred to the joint structures from non-weight bearing to full-weight bearing (Delahunt and Remus, 2019). Therefore, high impact forces and loading rates have been linked to ankle injury risk (Barrett et al., 1998; Radin and Paul, 1971; Schwellnus et al., 1990).

Shoes can influence ankle sprain risk by affecting impact peaks and loading rates transmitted through the ankle joint from landing. It is important to discuss the influence of shoes on landing mechanics since cheerleaders perform in shoes as opposed to gymnasts who perform barefoot. Shoe manufacturers often create shoes with varying midsole thicknesses and materials. Shoes with more midsole-cushioning material may be chosen by cheerleaders that specialize in tumbling or basing. On the other hand, flyers may choose shoes with minimal material (less cushioning) since added weight and bulk may impact performance. Malisoux and colleagues (2017) have reported decreases in vertical impact peaks and loading rate with shoes that feature more cushioning material. Another study observed lower impact peaks and tibial shock in shoes with more cushioning (Wei et al., 2018). Nigg et al. (1987) may not agree with the previous statement, but their study featured a running protocol, not landing. Additionally, Nigg et al. reported on heel striking in running and jumpers most likely land toes first. However, they did suggest a shoe's cushioning properties affect the direction of internal loading, which still may be applicable to jumpers.

There is also reason to believe surface properties alter impact forces and loading rates. Some studies have found softer landing surfaces reduce vertical impact peaks, while others found no significant effects (Malisoux et al., 2017; McNitt-Gray et al., 1993). However, most would agree softer and more compliant surfaces reduce loading rates (McNitt-Gray, 1993; Wei et al., 2010). During the sideline season, cheerleaders may perform skills on harder vinyl surfaces for basketball games or on grass/artificial turf for football games. During the competitive season, cheerleaders practice and perform on softer, 1 3/8-inch foam mats. Landing on a basketball court instead of a softer mat can increase stress on ankle structures upon landing and increase the risk of injury (Bagnulo, 2012). Additionally, external impact peaks have been related to joint reaction forces and torque, which also have been related to ankle injury risks (Xiao et al., 2017; Mills et al., 2010). Therefore, considering practice/performance surfaces and shoes in cheerleading is important since these athletes perform on a multitude of surfaces and tumble with different types of shoes. These surfaces and shoes then have an impact on an athlete's risk of injury. Although, cheerleading surfaces may have a greater impact on injury risk than shoes since cheerleading mats tend to be thicker than a shoe's midsole. Cheerleaders also tend to land in a toe-first manner when performing flipping tasks. Heavy toe-contact activities may not fully take advantage of a shoe's midsoles, which tends to be more heel-concentrated (Mai et al., 2021; Drougkas et al., 2018; Wunsch et al., 2017; Hoogkramer et al., 2018). Therefore, it may be more beneficial to investigate the effects of surfaces over shoes.

Ecological Validity of Current Landing Studies

Drop landing from a box is easy to perform and is desirable to investigators due to its simplicity. Most of the found articles that studied the effects of various shoes and surfaces on landing have used a drop landing protocol. Two shoe articles also used a drop jump task alongside drop landing (Wang et al., 2017; Schultz et al., 2012). However, six articles were found to include jump-landing and/or drop jump tasks alongside drop landing (Schwameder et al., 2013; Wang et al., 2017; Schultz et al., 2012) or solely using jump landing and/or drop jump tasks (Malisoux et al., 2017; DeBiasio et al., 2013; Bulter et al., 2014). Drop landing and jump landing tasks can be considered simple landing tasks, and some studies included more complex protocols. For example, one study that tested landing between different synthetic surfaces used a netball attack landing task for their protocol (landing on the dominant leg while catching a ball) (Steel and Milburn, 1988). Then, the studies that focused on landing in gymnasts and their various landing mats utilized more intricate landing tasks. Sands and colleagues (1991) had subjects hang from uneven bars and drop to their feet. A study that examined back arching with landing on different mats had gymnasts vault off a Swedish vaulting box (Too and Adrian, 1988). Wu and colleagues (2019) recorded the kinematics of a single gymnast performing a standing back salto. However, the case study kinematics were used for a computer simulation that tested back salto landing various simulated mats, and the gymnastic did not land on those tested mats personally. A similar study recorded the kinematics of a single gymnast performing a twisting back salto for a computer-simulated test on different landing mats (Xiao et al., 2017). Altogether, tumbling or flip landing protocols are scarce in surface property studies and are virtually non-existent in shoe studies.

Although drop landing may be easy for the sake of conducting a protocol, they may not fully replicate real-life landing. Studies have shown significantly different muscular responses, kinematics, and kinetics between drop landing and other vertical landing tasks (Afifi and Hinrichs, 2012; Edwards et al., 2009, Harty et al., 2011). These differences were both shown in the sagittal and frontal planes. Furthermore, the differences may be even starker between simple vertical landing and flip landing tasks. The earliest articles found to compare vertical landing tasks to flip landing tasks were two studies by Beatty and colleagues (2006, 2007). They compared vertical straight-jumps to tuck-jumps, round-offs, backhand springs, and a back tuck salto. Unfortunately, these papers were from conference proceedings and their results are limited. But, what they did report highlighted sagittal plane kinematic and ground reaction force discrepancies between the jumping and flipping skills. The results also suggested simple landing tasks may underestimate the complex attributes of flip landing. A paper by Comfort and colleagues also compared vertical landing to flip landing. They compared the landing frontal plane projection angles in drop landing, back tuck somersaults, and backaway dismounts from a bar (2016). Similar to Beatty et al. (2006, 2007), Comfort and colleagues (2016) found significant differences in frontal plane projection angles between tasks. This paper was also from a conference proceeding and the results were not discussed in great detail.

The literature contained scarce flip landing acticles. But, the few papers that were found may be more accurate in representing gymnastics and acrobatic landing than other drop landing studies. The two studies by Wu et al. (2019) and Xiao et al. (2017) may have only simulated flip landing and were vastly limited by single-subject kinematics, but the findings of Beatty et al. (2006, 2007) and Comfort et al. (2016) would suggest they may be more representative of real gymnastics landing characteristics. The ecological validity of using a simple task to represent landing in real-life is questionable, even if they are the popular methodological option. The ecological validity of simple landing protocols may be diminished further when studying landing in the gymnast/cheerleading population. Drop landing protocols may be desirable for their ease of use, but flip landing protocols may be more desirable if the goal is to truly replicate gymnastics landing in real-life.

Conclusion

Ankle sprain injuries appear to be alarmingly prevalent in the athletic population, especially in those who participate in jumping sports. Although cheerleading doesn’t have the highest recordings of overall injuries, the sport had the most injuries that caused prolonged time off from play. Ankle sprain can often cause prolonged time off from play as it is the most common injury in cheerleading. Athletes that sustain an ankle sprain injury may not take the appropriate time to heal and experience a recurrent injury. The literature highly suggests a history of ankle sprains is one of the most crucial predictors of a future ankle sprain injury. Since the mechanism of an inversion ankle sprain includes excessive and sudden plantar flexion and ankle inversion during a motion and increased plantar flexion and ankle inversion before and at initial contact. These mechanisms are most seen during landing from a tumbling pass, jump, or stunt within cheerleading. Other intrinsic risk factors can include having a higher BMI or body mass, strength imbalances, and deficits in balance and/or proprioception. Lastly, the extrinsic risk factors can include the type of sport played, the setting of play, the surface of play, and the type of shoe and/or orthosis worn.

High impact peaks and loading rates upon landing may also increase the risk of ankle injuries. Shoes and surfaces are believed to influence the risk of injury by influencing impact force peaks and loading rates. The literature suggests shoes and surfaces with less cushioning properties produce higher impact forces and loading rates. In contrast, shoes and surfaces with more cushioning properties attenuate these forces that can cause injury. Therefore, looking into shoes and surfaces in cheerleading is critical because cheerleaders perform on various surfaces, and cheerleaders are unique from gymnasts because they tumble in shoes. Shoes and surfaces may both affect cheerleading injury risk, but surfaces may have a have a greater impact since cheerleading mats tend to be thicker than a shoe’s midsole. In this case, studying the effects of surfaces may be more critical for this population. Current methods in testing the effects of shoes and surfaces on landing mechanics mainly utilize simple vertical drop landing tasks. Few studies in the literature have studied flip landing on various surfaces, and there were no found studies about flip landing and shoes. Some have documented discrepancies in the mechanics between a simple drop landing and more complex tasks. As a result, there may be issues in the ecological validity of generalizing drop landing to all other forms of landing, especially flip landing.

Chapter 3: Methods

The purpose of this study was to compare the effects of two cheerleading surfaces (hard vs. matted) between vertical drop landing and flip landing tasks. Participants performed simple vertical drop landing and flip landing tasks on a bare and matted force-plate surface. Three-dimensional motion capture and force plate data was helped evaluate the interactions of landing tasks and surfaces on landing characteristics.

Participants

Fourteen collegiate cheerleaders (eight females; six males) were recruited for this study (Table 2), but only 12 participants (7 females; 5 males) were included (Table 4). Subject 11 was excluded because they achieved only a single successful landing in the FLIP-HARD condition, and subject 9 was unable to complete the study. A power analysis of available landing data indicated that a minimum of 10 subjects should be sufficient to detect significant differences in kinematic and kinetic variables that are associated with increased ankle injury risk (Xiao et al., 2017; Afifi and Hinrichs, 2012; Beatty et al., 2007; Comfort et al., 2016; Wang et al., 2017). Participants were recruited from the University of Wisconsin-Milwaukee and the Marquette University cheerleading teams. Participants had at least one year of prior cheerleading experience and were active with a collegiate team within the last six months. Participants were sent an online questionnaire to complete upon expressing interest in the study. Ineligible factors the questionnaire screened for were conditions that prevent/interfere with normal execution of the study's tasks, pregnancy, inadequate experience, or inadequate skill level. All participants also provided video evidence showing adequate tumbling skills prior to participating in the study's activities. Subjects had on average 2.6 ± 1.5 years of collegiate cheer experience, and all included subjects identified as tumblers (Table 2). Additional identified positions varied between flyers, bases, and backspots.

Table 2. Participant demographic information.

Code	**Gender**	**Age (yrs)**	**Mass (Kg)**	**Height (m)**	**Overall Cheer Experience (yrs)**	**College Cheer Experience (yrs)**	**Position(s)**
S01	M	18	72.57	1.85	6	1	backspot, base, tumbler
S02	M	25	55.79	1.67	6	6	flyer, tumbler
S03	M	23	77.11	1.67	3	3	base, tumbler
S04	F	20	56.7	1.65	10	3	base, tumbler
S05	F	18	48.99	1.68	9	1	flyer, side-base, tumbler
S06	F	22	52.16	1.52	9	4	flyer, tumbler
S07	F	20	51.26	1.60	7	3	flyer, tumbler
S08	F	19	61.23	1.70	11	2	backspot, base, tumbler
S09	M	26	92.25	1.88	6	4	base, tumbler
S10	M	22	86.18	1.78	4	4	base, tumbler
S11	F	19	63.5	1.73	10	1	backspot, tumbler
S12	F	21	47.63	1.55	2.5	1	flyer, tumbler
S13	M	22	72.57	1.75	6	2	backspot, base, tumbler
S14	F	19	56.70	1.65	4	2	base, tumbler
Mean		21.0	64.5	1.7	6.7	2.6	
SD		2.5	14.5	0.1	2.8	1.5	

Instrumentation and Equipment

A ten-camera Motion Analysis Eagle System (Motion Analysis Corp., Santa Rosa, CA, USA) was used to obtain lower extremity kinematics by tracking the trajectories of retro-reflective markers at 200 Hz. Kinetic variables was obtained using two Bertec force plates (Bertec, Inc., Columbus, OH, USA) at 1000 Hz. These two systems collected data synchronously in Motion Analysis Cortex. Participants wore their personal cheerleading shoes during data collection. The landing surfaces were the bare force plate surface for the hard surface condition (HARD), and a 1-3/8” cheerleading mat placed over the force plates for the matted condition (MAT). A height-adjustable platform was used for the drop landing task. Visual 3D (C-Motion Inc, Germantown, MD, USA) was used for data processing, and Matlab (MathWorks Inc., Natick, MA, USA) was used to extract dependent variables and perform statistical analyses.

Experimental Protocol

Upon arrival, each participant was asked to show video evidence of their tumbling skills to confirm they were capable to perform the study’s tasks. Information about the participant’s sex, height, and weight was collected prior to data collection. Participants were also asked to warm up for 15 minutes before the landing tasks by lightly jogging on a treadmill, stretching, or doing any other activities they may normally do before practices. Once the participant was adequately warmed-up, they were asked to perform three-to-five practice round-off, back tucks (the flipping task) to become comfortable with the tumbling surface, and to calibration their starting position on the runway. Retro-reflective markers and cluster sets were applied to the subject’s lower extremity and torso after the practice tumbling passes. Extra adhesive strips were used to secure the markers. The individual markers were placed on the anterosuperior and posterosuperior iliac spines, iliac crests, and greater trochanters. Markers were also placed on the right lateral and medial femoral epicondyles, lateral and medial malleoli, and the heads of the first and fifth metatarsals. The clusters were strapped onto the right lateral thigh and shank, roughly at mid-length. After a brief standing calibration, the markers on the iliac crests, greater trochanters, femoral epicondyles, and malleoli were removed.

The study's tasks included a round-off, back tuck flipping task (FLIP), and a vertical drop landing task (VERT). Surface conditions for both tasks included landing on a 1-3/8" cheerleading mat (MAT) that was cut and placed over two force plates and the bare force plate surface (HARD). For logistical reasons, all data collections started with participants in the FLIP-MAT condition. Participants performed the FLIP task over the mat until three successful landing trials were collected. A successful trial must include successful execution of the tumbling task and a clean force plate landing. A clean force plate landing was described as the right foot landing fully on the single force plate (the force plate that is most orientated to the right side of the body when landing), no parts of the right foot crossing over the force plate edge and/or crossing over onto another force plate, and no parts of the left foot crossing over onto the force plate that the right foot is on. Stepping off the force plates before the end of the landing deceleration phase also counted as an unsuccessful trial. The landing deceleration phase was defined as the initial contact to maximal knee flexion. Even though the goal was two collect three successful landings, a maximum of 10 attempts was included to prevent fatigue and the onset of muscle soreness.

After three successful FLIP-MAT trials were collected or the maximum attempts were reached, participants performed the VERT-MAT condition. Participants stepped off a height-adjustable platform with their right foot and landed with both feet onto the mats covering the two force plates below (one foot on each plate). The drop height, or the platform level the participant stepped off from, was determined by the peak right PSIS marker height during the flight phase of the FLIP task. The peak right PSIS height was used to approximate COM displacement during flipping to better compare the two tasks. The platform height that most closely matched the peak right PSIS flight height minus the impact right PSIS height was chosen. Participants performed the VERT-MAT task until three successful landing trials were collected up to a maximum of 10 attempts.

After completion of the MAT tasks, the cheerleading mats were removed. Participants then repeated the FLIP task over the HARD surface. Participants performed the FLIP-HARD task until three successful landing trials were collected up to a maximum of 10 attempts. Lastly, participants performed the VERT task over the HARD surface. Participants performed the VERT-HARD task until three successful landing trials were collected up to a maximum of 10 attempts.

Data Reduction

Three-dimensional joint positions and ground reaction forces (GRF) were collected from the start of the tumbling pass or drop-landing and throughout the duration of landing. The kinematic and kinetic data was filtered using a 4th order, zero-lag, low-pass Butterworth filter with a cut-off frequency of 15 Hz and 50 Hz, respectively. Residual analyses indicated these cut-off points were appropriate for our data (Winter, 2009). Thigh, shank, and foot coordinate systems were established from the standing calibration trial. The X-axis was orientated mediolaterally, the Y-axis was orientated anteroposteriorly, and the Z-axis was orientated inferosuperiorly. Joint angles were calculated using the joint coordinate system approach (Grood and Suntay, 1983). This was done for knee and ankle kinematics. Knee and ankle flexion/extension or dorsiflexion/plantar flexion was motion along the X-axis in the sagittal plane. Knee and ankle abduction/adduction or eversion/inversion was motion along the Y-axis in the frontal plane. Joint kinetics was calculated using inverse dynamics analyses (Bresler and Frankel, 1950). Segment center of mass (COM) velocities and accelerations and joint velocities was calculated using the first central difference method. Body segment parameters proposed by Dempster (1955) and the subject's total body weight (BW) was used to gather body segment inertial properties to calculate knee and ankle moments. All data processing was done in Visual 3D for all successful trials in each task and surface condition.

To assess the similarity in task demands, the vertical velocity of the foot segment COM at impact was extracted from the data. In addition, it was discovered after the completion of data collection that the foot markers were observable during the takeoff of the flip. This allowed for an estimation of flight time, and thereby flight height and the impact velocity of the center of mass based on Newtonian physics. Furthermore, comparing the foot velocity during the tasks to the COM velocity during the flip task allowed for a quantification of the effect of the rotation of the body on impact velocity of the leg.

Joint kinematics, kinetics, and GRF was extracted from initial contact (IC) to the point of maximal knee flexion during landing. This represented deceleration during landing before the recovery phase. The maximal vertical GRF represented the peak impact force. Instantaneous loading rates were calculated using the first central difference method, and the peak value was reported as the maximum loading rate (Bus, 2003). All GRF values were normalized to BW. The IC position was defined as the joint position when the vertical ground reaction force exceeds the threshold of 10 N (Malisoux et al., 2017, Wu et al., 2019, Christoforidou et al., 2017). Knee and ankle angles at IC and ROM in the frontal and sagittal plane were extracted from this time period. Joint range of motion was defined as the absolute value of the maximum joint angle during the landing deceleration period minus the joint angle at initial contact. Lastly, peak knee extension and abduction, and ankle plantar flexion and eversion moments were extracted from the landing deceleration phase. All moments were normalized to body mass. Although all data was analyzed from IC to maximal knee flexion, graphical depiction of the variable time series show the first 100 ms after IC, as this period is critical for injury occurrences (Fong et al., 2012; Hewett et al., 1999). The average time to max maximal knee flexion is around the first 100 ms during the FLIP tasks but appears later during the VERT tasks (Table 3). All data extraction was done in Matlab for all successful trials in each task and surface condition.

Statistical Design and Analysis

Repeated measures ANOVAs with 2x2 designs for landing tasks and surface conditions were conducted for dependent variables of this study (Schurger, 2022). Normality analyses have indicated that using ANOVAs were appropriate. The primary dependent variables for this study were frontal plane ankle kinematics and moments. Additionally, three-dimensional ankle and knee joint kinematics, kinetics, ground reaction forces, and segment velocities were analyzed. For significant tasks and surface interactions, pairwise comparisons were made using paired t-tests. A significance level of $\alpha = 0.05$ was utilized for all statistical analyses. All statistical analyses were performed in Matlab.

Chapter 4: Results

All subjects had six successful VERT trials and most had six successful FLIP trials (Table 3). However, three subjects were only able to achieve five successful FLIP trials in the allotted attempts.

Table 3. Successful task trials and time from IC to maximal knee flexion.

	# Successful Trials		Mean Time to Max Knee Flexion (ms)	
Subject #	**FLIP**	**VERT**	**FLIP**	**VERT**
S01	6	6	118	116
S02	6	6	152	138
S03	6	6	200	167
S04	6	6	101	195
S05	5	6	175	221
S06	6	6	133	148
S07	6	6	108	205
S08	6	6	113	134
S10	5	6	175	490
S12	6	6	83	148
S13	5	6	150	305
S14	6	6	131	212
Mean	5.8	6	136.6	206.6
SD	0.5	0.0	34.8	103.1

Vertical Foot Velocity at Initial Contact

There was no significant interaction between task and surface. However, the vertical foot velocity magnitude at IC was roughly twice as large when subjects performed FLIP tasks compared to VERT tasks (Table 4). There were two identified reasons for the large difference (Table 5). The first is that the body's angular velocity during the FLIP task added ~1.7 m/s to the impact velocity of the foot compared to the estimated COM impact velocity. The other factor was imperfections in setting the platform height and the inconsistencies in how subjects stepped off the box. The VERT platform height turned out to be ~0.06 m lower than the actual COM displacement observed during FLIP. In reviewing how subjects performed the drop test, it was also found that some subjects slightly lowered their COM before leaving the platform. Combined, these led to a reduction in foot velocity by ~0.7 m/s relative to the COM impact velocity during the FLIP task. However, ~70% of the vertical foot velocity difference between tasks was due to the body's rotation during the FLIP task. The vertical foot velocity was also significantly larger when landing on the MAT surface compared to the HARD surface by ~0.3 m/s (Table 4).

Table 4. Impact peak forces during landing, peak loading rates of the impact peaks, and the vertical foot velocities at initial contact.

		Impact Peak Force (BW)	**Peak Loading Rate (BW/s)**	**Vertical Foot Velocity at IC (m/s)**
Flip	Mat	7.0 (1.9)	628.1 (221.3)	-5.2 (0.5)
	Hard	6.4 (1.1)	674.7 (178.3)	-4.9 (0.5)
	Mean	6.7 (1.5)	651.4 (179.7)	-5.0 (0.5)
Vert	Mat	3.9 (1.2)	217.2 (72.5)	-2.7 (0.4)
	Hard	3.6 (0.8)	310.0 (93.8)	-2.5 (0.3)
	Mean	3.8 (0.8)	263.6 (74.6)	-2.6 (0.3)
Overall	Mat	5.5 (1.4)	422.6 (126.8)	-4.0 (0.3)
	Hard	5.0 (0.8)	492.3 (121.1)	-3.7 (0.3)
	Task*Surface	$p = .358$	$p = .376$	$p = .362$
		$\eta_p^2 = .077$	$\eta_p^2 = .071$	$\eta_p^2 = 0.075$
	Task	$p < .001$*	$p < .001$*	$p < .001$*
		$\eta_p^2 = .870$	$\eta_p^2 = .864$	$\eta_p^2 = .952$
	Surface	$p = .134$	$p = .046$*	$p = .001$*
		$\eta_p^2 = .191$	$\eta_p^2 = .313$	$\eta_p^2 = .608$

* Denotes significant effect ($p < .05$)

Table 5. Subject FLIP flight height, platform height configuration, and the vertical velocity differences (at the COM and distal foot) when performing FLIP and VERT tasks.

	FLIP				VERT		
Subject	**COM Height (m)**	**COM Vel (m/s)**	**Foot Vel (m/s)**	**Rotational Difference (m/s)**	**Platform Height (m)**	**Foot Vel (m/s)**	**Task Difference (m/s)**
S01	0.6	3.5	5.4	2.0	0.36	2.5	-1.0
S02	0.35	2.6	4.8	2.2	0.29	2.4	-0.2
S03	0.50	3.1	5.8	2.7	0.39	2.4	-0.8
S04	0.64	3.5	4.9	1.4	0.64	3.1	-0.4
S05	0.67	3.6	4.9	1.2	0.59	2.8	-0.8
S06	0.57	3.3	4.3	0.9	0.45	2.4	-0.9
S07	0.52	3.2	5.4	2.2	0.42	2.4	-0.8
S08	0.54	3.3	4.8	1.5	0.42	2.4	-0.9
S10	0.56	3.3	5.5	2.1	0.64	2.9	-0.5
S12	0.52	3.2	4.5	1.3	0.62	2.9	-0.3
S13	0.7	3.7	5.5	1.8	0.74	3.2	-0.5
S14	0.5	3.2	4.9	1.7	0.50	2.3	-0.9
Mean	0.56	3.3	5.0	1.7	0.50	2.6	-0.7
SD	0.09	0.3	0.5	0.5	0.14	0.3	0.3

Ground Reaction Force

Six subjects showed double peaks in the GRF during the FLIP tasks, while others only showed single peaks (Figure 1). In the VERT tasks, nine subjects showed double peaks in the GRF, while others only showed single peaks. For those subjects with double peaks, the second peak was extracted as the dependent variable. The average GRF profile during the FLIP tasks demonstrates substantially faster rise in force and reaches a greater peak, averaging across subjects resulted in an ensemble curve, particularly for the FLIP task, that was not necessarily representative of individual behaviors due to the variability in patterns (Figure 2). The statistical analysis yielded no significant interactions between tasks and surfaces for either the impact peak or loading rate (Table 4). However, both the impact peaks and loading rates were significantly greater during the FLIP task. The peak GRF was 76% greater, and the loading rate was 147% greater (Figures 3 and 4). In addition, the loading rate was significantly greater on the HARD surface, although there were no surface differences in the impact peaks.

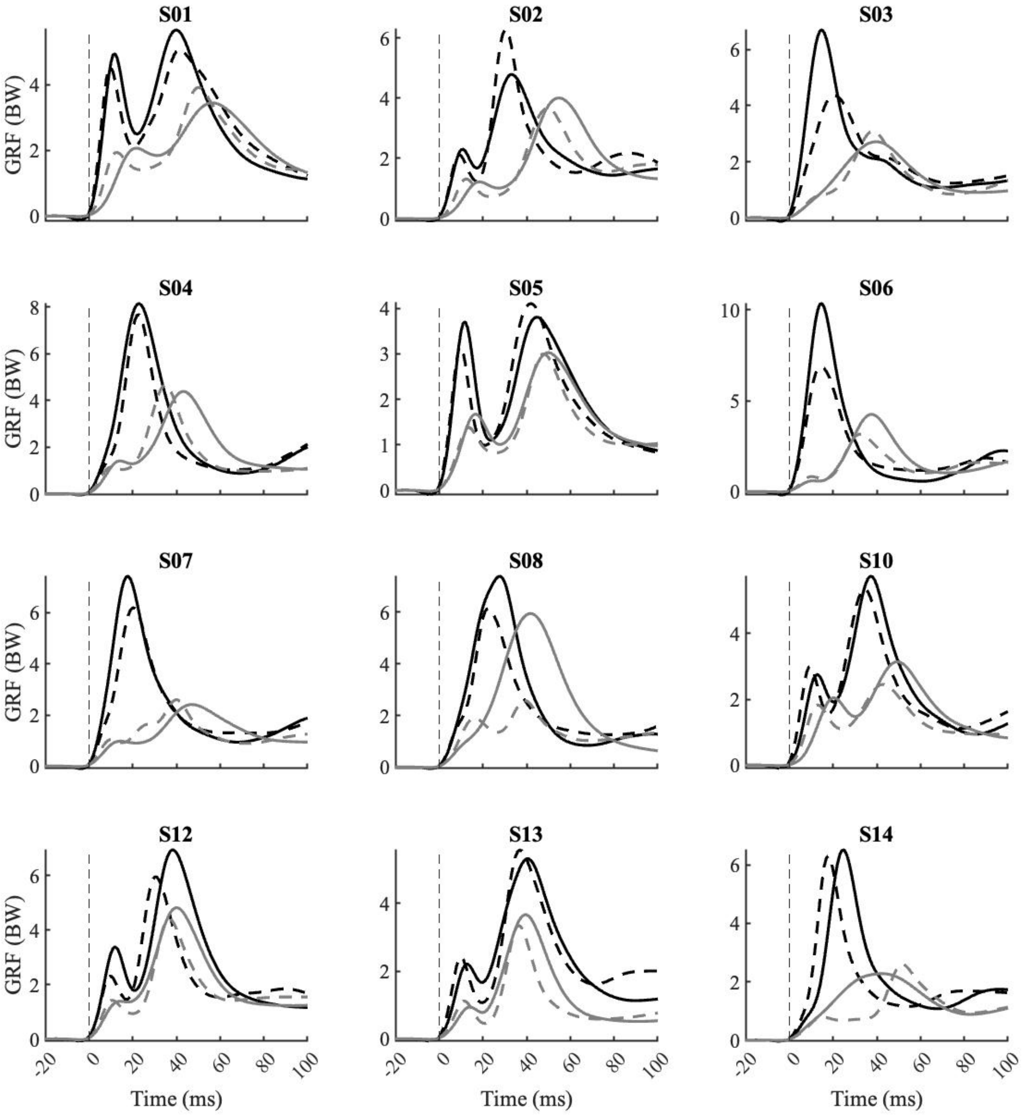

Figure 1. Individual subject average ground reaction force from 20 ms before initial contact to 100 ms after initial contact. Black line = FLIP, grey line = VERT, solid line = MAT, and dashed line = HARD. The vertical dashed line at 0 ms indicates initial contact.

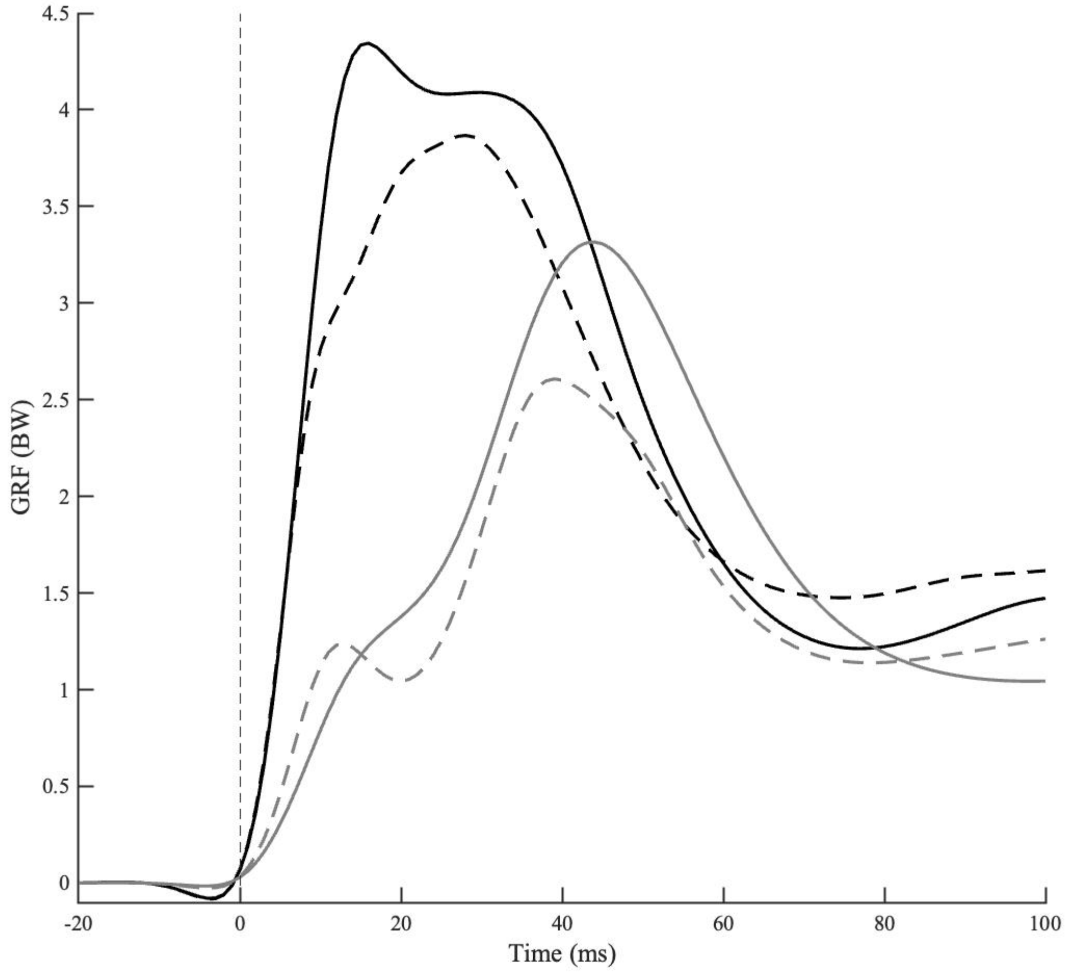

Figure 2. Mean of subject average ground reaction force from 20 ms before initial contact to 100 ms after initial contact. Black line = FLIP, grey line = VERT, solid line = MAT, and dashed line = HARD. The vertical dashed line at 0 ms indicates initial contact.

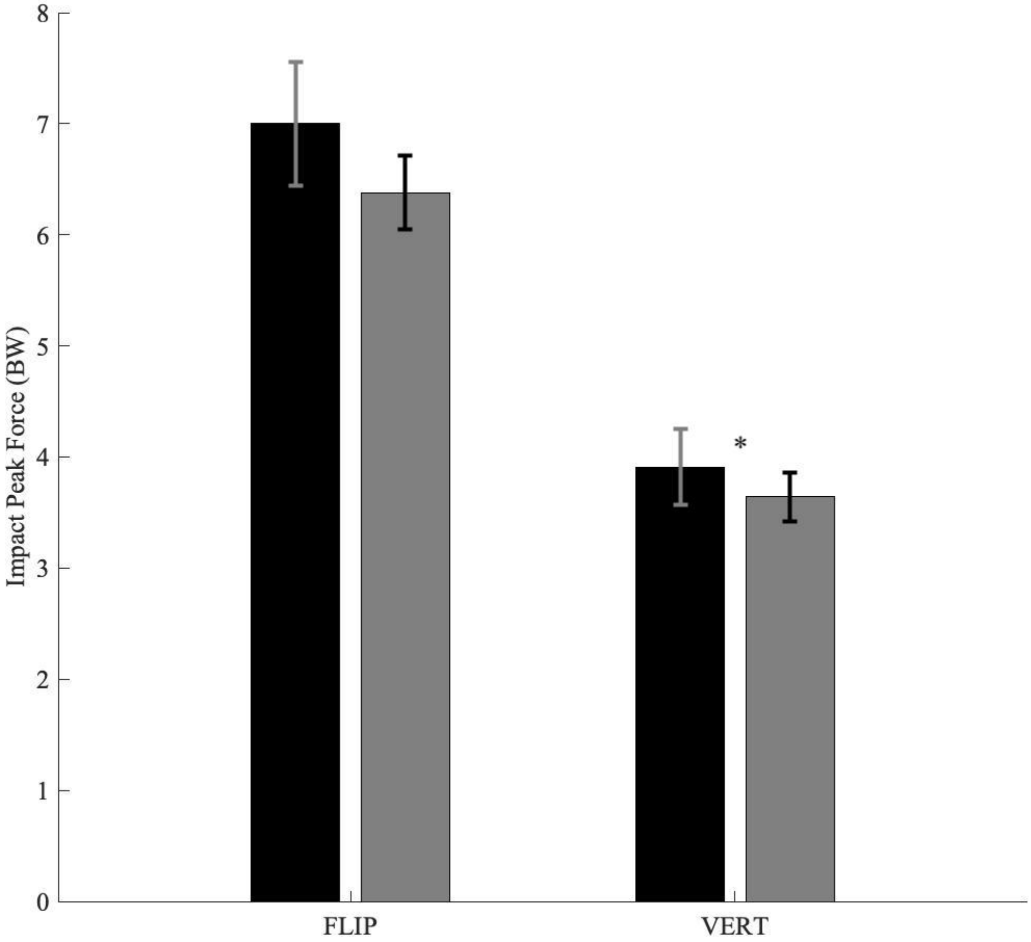

Figure 3. Impact peak forces in BW. Black bar = MAT, grey bar = HARD. * Denotes significant task effect.

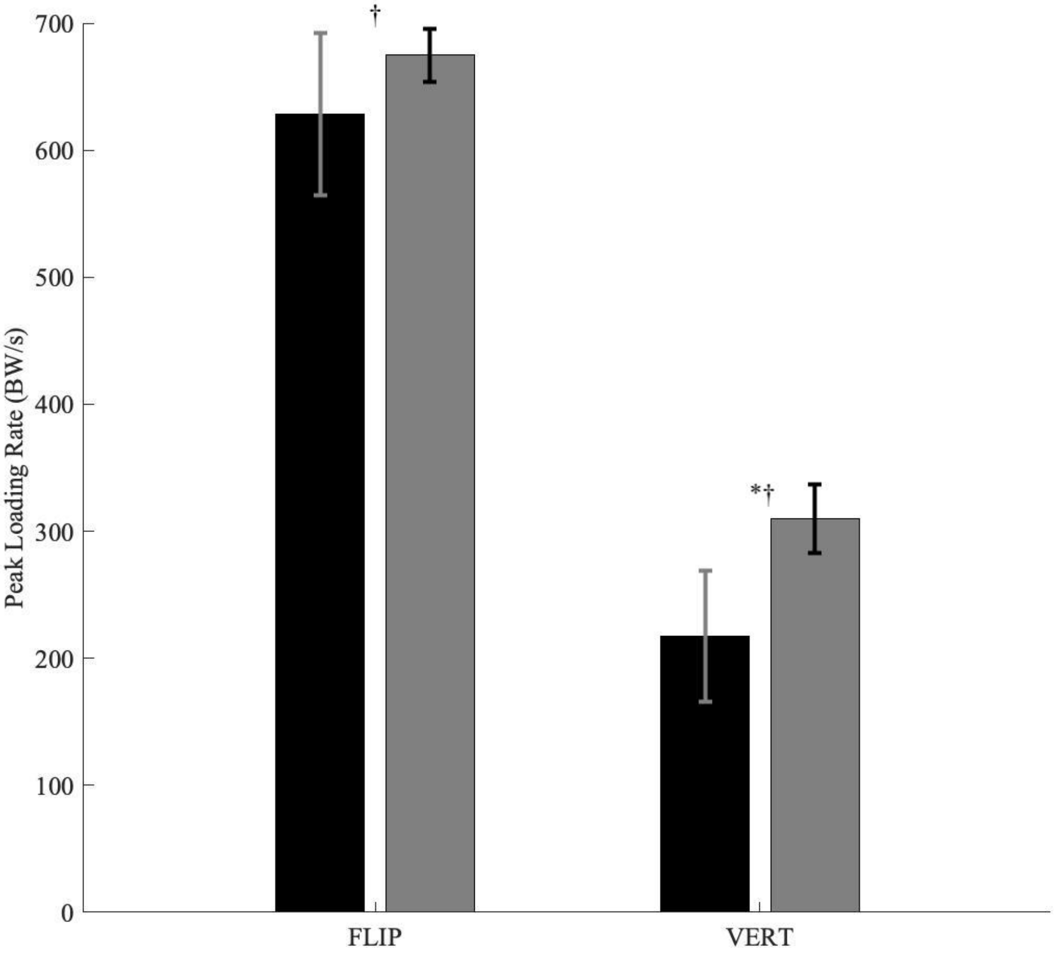

Figure 4. Peak loading rates in BW/s. Black bar = MAT, grey bar = HARD. * Denotes significant task effect. † Denotes significant surface effect.

Joint Kinematics

Participants demonstrated similar patterns of knee flexion and ankle dorsiflexion in both tasks, although the ankle tended to be more plantar flexed at IC during the VERT task (Figure 5). In the frontal plane, participants abducted at the knee and everted at the ankle during the landing phase. No kinematic variables had significant interactions between tasks and surfaces (Table 6 and Table 7). In the sagittal plane, there was no difference in knee flexion angle at IC between tasks, but the ankle was significantly more plantar flexed at IC during the VERT landings. The knee was significantly more flexed at IC during HARD landings, but there was no difference in ankle plantar flexion at IC between surfaces. In the frontal plane, the knee was significantly more adducted at IC during the FLIP task, but there were no differences in ankle position between tasks. The ankle was significantly more inverted at IC on the HARD surface, but there were no differences in knee frontal plane position at IC due to surface. There were no significant task or surface effects for any ROM variables (Table 7). Although, there were potential trends of greater sagittal knee and ankle ROM on the HARD surfaces (p = .053 and .056, respectively).

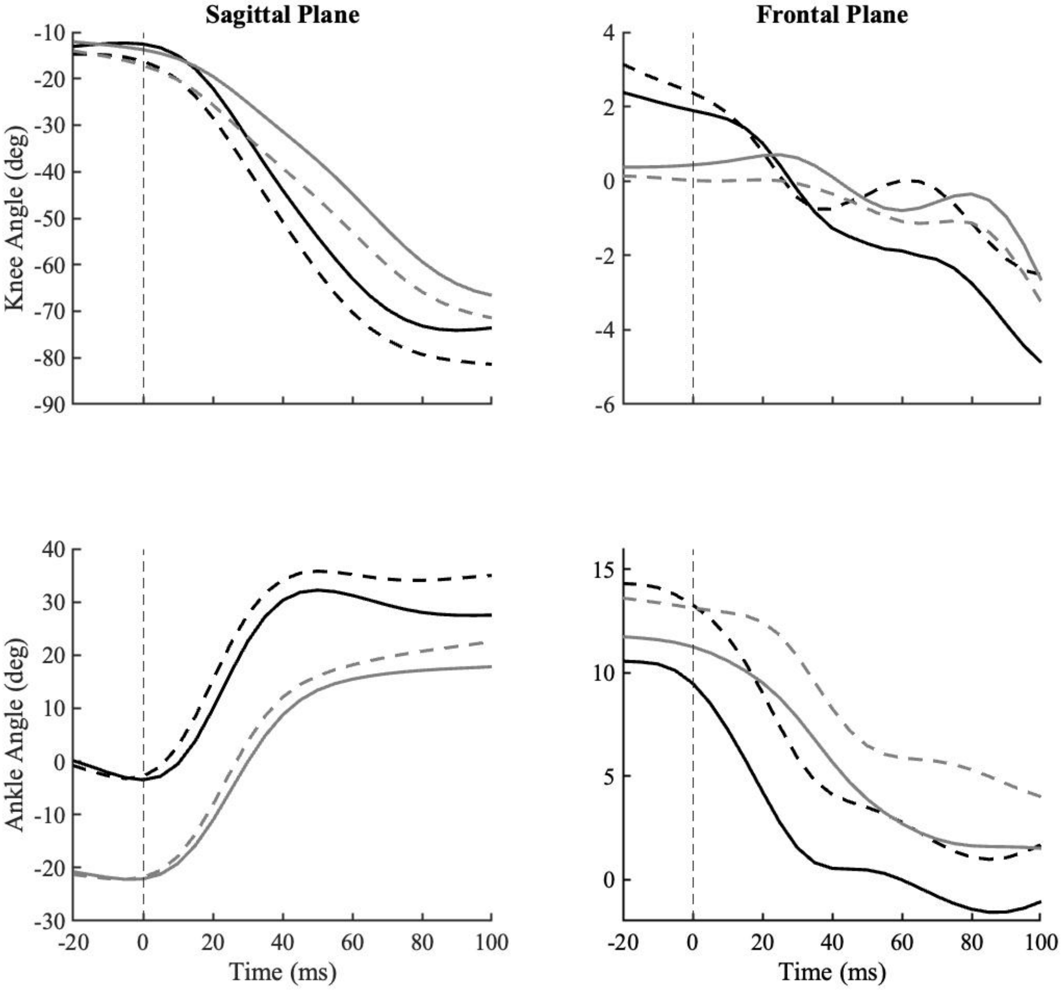

Figure 5. Joint kinematics from 20 ms before initial contact to 100 ms after initial contact. A) Sagittal knee angles, B) frontal knee angles, C) sagittal ankle angles, and D) frontal ankle angles. Black line = FLIP, grey line = VERT, solid line = MAT, and dashed line = HARD. The vertical dashed line at 0 ms indicates initial contact.

Table 6. Knee and ankle angles at initial contact.

		Sagittal IC Angle (deg)		**Frontal IC Angle (deg)**	
		Knee	**Ankle**	**Knee**	**Ankle**
Flip	Mat	-12.6 (5.2)	-3.5 (16.1)	1.9 (2.6)	9.5 (5.2)
	Hard	-16.3 (5.1)	-2.8 (12.6)	2.4 (3.0)	13.3 (5.8)
	Mean	-14.4 (4.9)	-3.1 (13.8)	2.1 (2.7)	11.4 (5.1)
Vert	Mat	-13.8 (7.7)	-22.1 (7.9)	0.4 (2.7)	11.3 (3.8)
	Hard	-17.1 (7.1)	-21.8 (6.7)	0.0 (2.5)	13.1 (3.7)
	Mean	-15.50 (7.0)	-22.0 (6.6)	0.2 (2.5)	12.2 (3.6)
Overall	Mat	-13.2 (5.6)	-12.8 (10.9)	1.2 (2.4)	10.4 (4.2)
	Hard	-16.7 (5.5)	-12.3 (8.5)	1.2 (2.5)	13.2 (4.3)
	Task*Surface	$p = .794$	$p = .888$	$p = .115$	$p = .158$
		$\eta_p^2 = 0.006$	$\eta_p^2 = .001$	$h_p^2 = 0.209$	$h_p^2 = .172$
	Task	$p = .539$	$p < .001$*	$p = .009$*	$p = .444$
		$\eta_p^2 = .035$	$\eta_p^2 = .753$	$h_p^2 = .476$	$h_p^2 = .053$
	Surface	$p = .003$*	$p = .798$	$p = .891$	$p = .002$*
		$\eta_p^2 = .565$	$\eta_p^2 = .753$	$h_p^2 = .001$	$h_p^2 = .581$

* Denotes significant effect ($p < .05$)

Table 7. Knee and ankle ROM during landing.

		Sagittal ROM (deg)		**Frontal ROM (deg)**	
		Knee	**Ankle**	**Knee**	**Ankle**
Flip	Mat	67.8 (10.6)	37.8 (16.6)	8.1 (3.7)	13.8 (7.3)
	Hard	71.3 (11.7)	41.7 (13.5)	8.0 (4.7)	14.9 (4.9)
	Mean	69.5 (10.6)	39.7 (14.6)	8.1 (3.7)	14.4 (5.8)
Vert	Mat	59.9 (12.8)	45.0 (7.6)	7.5 (5.0)	12.7 (4.0)
	Hard	63.8 (9.2)	49.1 (5.6)	7.6 (5.4)	12.2 (4.0)
	Mean	61.9 (10.5)	47.0 (5.6)	7.6 (4.9)	12.5 (3.7)
Overall	Mat	63.8 (8.6)	41.4 (10.3)	7.8 (4.0)	13.3 (5.0))
	Hard	67.6 (7.4)	45.4 (7.9)	7.8 (4.6)	13.6 (3.6)
	Task*Surface	$p = .835$	$p = .943$	$p = .902$	$p = .311$
		$\eta_p^2 = .004$	$\eta_p^2 < .001$	$\eta_p^2 = 0.001$	$\eta_p^2 = .092$
	Task	$p = .106$	$p = .095$	$p = .537$	$p = .242$
		$\eta_p^2 = .219$	$\eta_p^2 = .232$	$\eta_p^2 = .035$	$\eta_p^2 = .121$
	Surface	$p = .056$	$p = .053$	$p = .978$	$p = .758$
		$\eta_p^2 = .292$	$\eta_p^2 = .298$	$\eta_p^2 < .001$	$\eta_p^2 = .008$

* Denotes significant effect ($p < .05$)

Joint Kinetics

Participants demonstrated similar patterns of knee extension and ankle plantar flexion moments in both tasks, although peak knee extension and ankle plantar flexion moments appeared earlier during FLIP tasks (Figure 6). In the frontal plane, participants showed knee abduction and eversion moments during the landing phases in both tasks. Peak frontal moments also occurred earlier during the FLIP tasks. The peak sagittal ankle moment was the only joint kinetic variable to have a significant interaction between task and surface ($p = .006$) (Table 8). The peak plantar flexor moment was greater on the HARD surface during the FLIP tasks, but there were no differences during the VERT tasks. (Figure 7). No other differences in joint moments were observed between surfaces. There were potential task and surface interactions trends for frontal plane ankle moments, although this was not significant ($p = .056$) (Table 8). All peak moments in the sagittal and frontal planes were greater during the FLIP tasks.

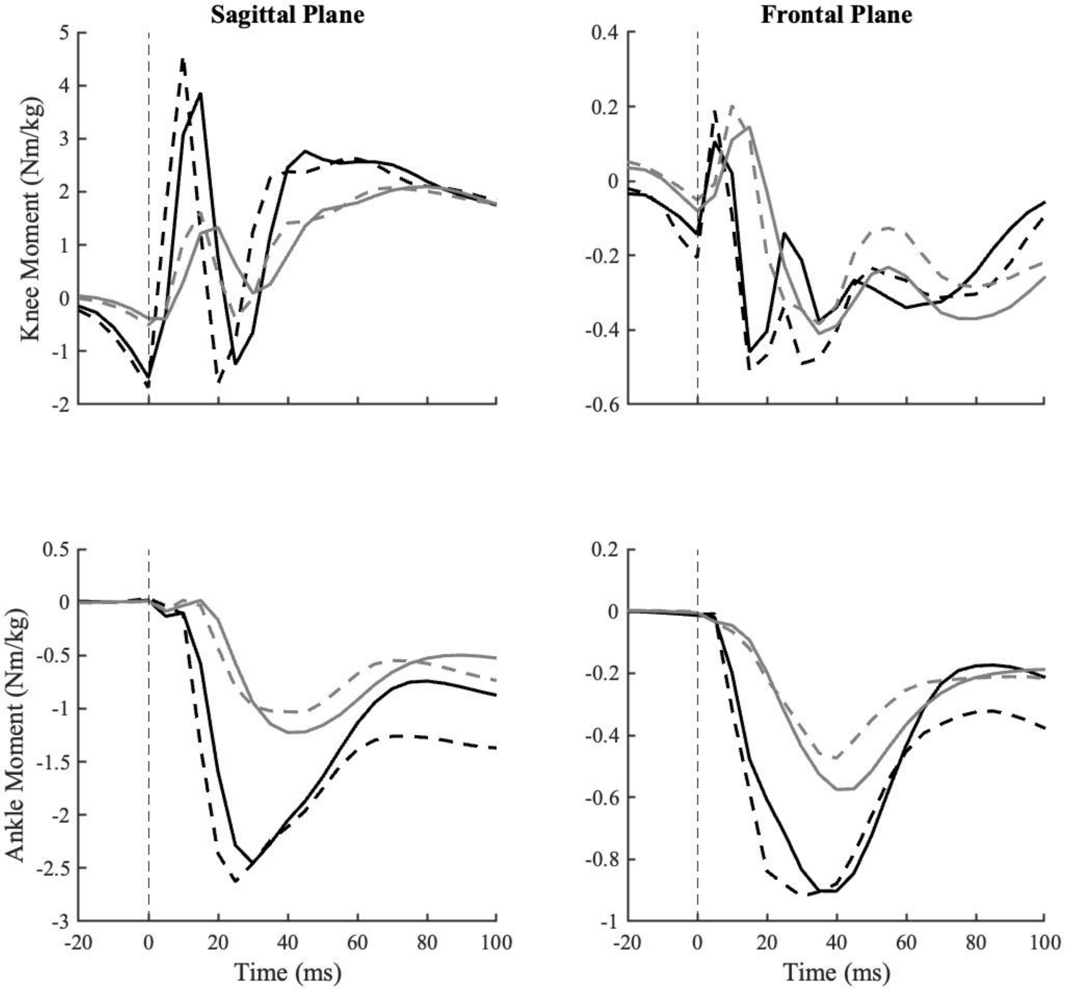

Figure 6. Joint moments from 20 ms before initial contact to 100 ms after initial contact. A) Sagittal knee moments, B) frontal knee moments, C) sagittal ankle moments, and D) frontal ankle moments. Black line = FLIP, grey line = VERT, solid line = MAT, and dashed line = HARD. The vertical dashed line at 0 ms indicates initial contact.

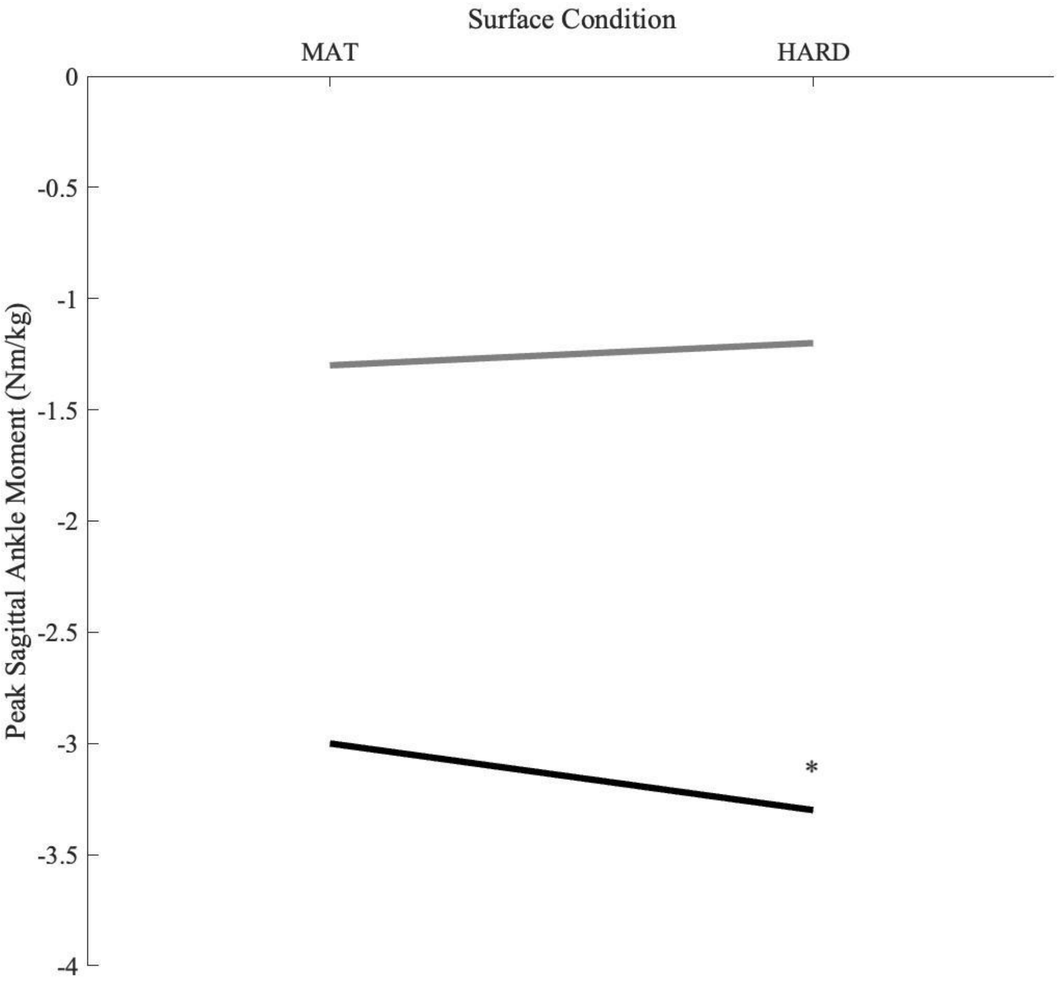

Figure 7. The effects of surfaces on peak sagittal ankle moments between tasks. Black line = FLIP task, and grey line = VERT task. * Denotes significant effect (p < .05).

Table 8. Peak moments at the knee and ankle during landing.

		Peak Sagittal Moments (Nm/kg)		**Peak Frontal Moments (Nm/kg)**	
		Knee	**Ankle**	**Knee**	**Ankle**
Flip	Mat	4.8 (2.1)	-3.0 (1.0)	-1.0 (0.2)	-1.3 (0.8)
	Hard	4.9 (2.4)	-3.3 (1.0)	-1.1 (0.5)	-1.4 (0.7)
	Mean	4.9 (2.2)	-3.1 (1.0)	-1.1 (0.3)	-1.3 (0.7)
Vert	Mat	2.4 (0.6)	-1.3 (0.6)	-0.7 (0.2)	-0.7 (0.3)
	Hard	2.5 (0.7)	-1.2 (0.5)	-0.6 (0.3)	-0.6 (0.3)
	Mean	2.4 (0.6)	-1.3 (0.5)	-0.7 (0.2)	-0.6 (0.3)
Overall	Mat	3.6 (1.3)	-2.1 (0.7)	0.8 (0.2)	-1.0 (0.5)
	Hard	3.7 (1.5)	-2.3 (0.7)	-0.9 (0.3)	-1.0 (0.5)
	Task*Surface	$p = .930$	$p = .006$*	$p = .293$	$p = .056$
		$\eta_p^2 < .001$	$\eta_p^2 = .504$	$\eta_p^2 = 0.099$	$\eta_p^2 = .292$
	Task	$p < .001$*	$p < .001$*	$p < .001$*	$p = .001$*
		$\eta_p^2 = .677$	$\eta_p^2 = .896$	$\eta_p^2 = .739$	$\eta_p^2 = .603$
	Surface	$p = .443$	$p = .117$	$p = .635$	$p = .941$
		$\eta_p^2 = .054$	$\eta_p^2 = .207$	$\eta_p^2 = .021$	$\eta_p^2 < .001$
Surface Effects Within Tasks	Flip		$p = .007$*		
	Vert		$p = .245$		

* Denotes significant effect ($p < .05$)

Chapter 5: Discussion

The purpose of this study was to compare the effects of two cheerleading surfaces (hard vs. matted) between vertical drop landing and flip landing tasks. The first hypothesis of this study was that impact peaks and loading rate would be greater when landing from the FLIP tasks and on the HARD surface. Impact peaks and loading rates were greater when landing from the FLIP tasks, but the surface conditions only affected the loading rate. Therefore, this hypothesis was partially supported. The second hypothesis was that sagittal and frontal plane kinematic variables would be greater when landing from the FLIP task and on the HARD surface. Knee adduction at IC was greater during FLIP task, but ankle plantar flexion was less. Knee flexion and ankle inversion at IC were greater on the HARD surface. Then, neither sagittal nor frontal plane ROM differed between tasks or surfaces. Therefore, hypothesis was also partially supported. Lastly, the third hypothesis was that peak sagittal and frontal plane moments would be greater when landing from the FLIP task and on the HARD surface. Peak knee extension and abduction, and ankle plantar flexion and eversion moments were all greater during FLIP landings, but there were no differences between surfaces. Like the others, the third hypothesis was partially supported.

An assumption of the study was that the impact velocity of the COM would be the same across the tasks, such that any differences would be due to task or surface effects. This assumption was tested by estimating the COM impact velocity during the FLIP task and comparing that to the impact velocity of the foot across all tasks. This yielded a complex picture. The combination of the angular velocity during the flip task and the imperfections in trying to match the flight height for the VERT task led to a substantial difference in the impact velocity of the feet. The angular velocity of the FLIP tasks increased the tangential velocity of the distal segments and overall vertical velocity of the foot. Then, the reduction in foot velocity relative to the FLIP task was likely due to two factors. First, we used the peak PSIS flight height during FLIP to estimate an appropriate drop height, which may not entirely correlate to the true COM height during FLIP. Secondly, we noticed participants sometimes lowered their COM prior to stepping off the platform during VERT trials. Despite the potential error-based differences, the angular component of flipping affected the impact velocities more than the imperfections in the VERT task execution and the task-surface comparisons are believed to be valid.

Furthermore, the discrepancy in impact velocities may also explain the loading differences between FLIP and VERT, especially within the ground reaction force variables. Our FLIP loading characteristics may look entirely different from other landing papers that only utilize vertical tasks because most other studies have not captured the angular component of flip landing. For example, Wu and colleagues (2019) showed GRFs up towards 12 BW when their gymnast performed standing back saltos (or back tuck). This was higher than GRF peaks of around 8 BW that McNitt-Gray et al. (1993) reported when individuals drop landed from 1.82 m. Although these GRF magnitudes may be relatively close, the differences that make them incomparable may lie in the landing heights and angular components. Standing back saltos do not utilize a running start or handsprings for added momentum. So, they may only reach the heights of typical vertical jumps. Vanezis and Lee (2005) have shown that elite jumpers only reach heights around .6 m, indicating the landing height difference between Wu et al.'s back salto and McNitt-Gray et al.'s vertical task is ~ 1.22 m. Yet, Wu et al. reported greater GRF peaks. That may mean impact velocity of the back salto task was significantly greater than that of the vertical task at higher heights due to the different angular velocities. This would then explain the discrepancies in loading parameters between the two studies. The differences observed between these two studies are also trends observed within our current data. Our current results with the results of previous studies would question the validity of using purely vertical tasks to summarize landings within an acrobatic population.

While there are limited studies with which to compare the FLIP task mechanics, the landing mechanics of the VERT task can be compared to several studies. Wang and colleagues (2017) reported peak forces of 2.74-3.59 BW for vertical drop landing heights were between 45 and 60 cm. This is similar to our average VERT impact peak force of 3.8 BW at the average drop height of 50.5 cm. Their loading rates of 208.5-251.2 BW/s were also similar to our average VERT loading rate of 263.3 BW/s. A flipping simulation study showed impact peaks slightly higher than our FLIP impact peaks (~9 BW compared to 6.7 BW), but this may have been due to the addition of a back-handspring that allowed their subject to achieve higher flight heights (Xiao et al., 2017). Like Afifi and Hinrichs (2012) and Edwards et al. (2009), our impact peak forces and loading rates significantly differed between landing tasks. However, we found the changing the surface from HARD to MAT mitigated only the loading rates but had no effect on impact peaks. This finding was similar to McNitt-Gray et al. (1993) and Malisoux et al. (2017), which showed lower loading rates and no difference in impact peaks when surface cushioning properties increased. Studies that have examined the effects of shoe midsole materials on GRF variables have also showed similar trends (Clarke et al., 1983; Nigg et al., 1987). The results of this study, tied with others, suggest that FLIP tasks increase ground reaction force parameters. Although, the surface may be more important for modulating loading rates than impact peaks. High impact forces and loading rates are generally linked to greater injury risk (Barrett et al., 1998; Radin and Paul, 1971; Schwellnus et al., 1990). Therefore, this study also suggests FLIP tasks and landing on a harder surface may increase ankle injury risks.

An interesting parameter of the FLIP tasks was double peaks in the GRF curves that half of our participants displayed (Figure 1). These double peaks differ from the single peaks that flip-simulation papers have reported (Wu et al., 2019; Xiao et al., 2017). However, those papers have only collected flipping data from a single person. The occurrence of a double peak may vary from person to person, as only half of our subjects displayed such behavior, although the majority of our subjects showed double peaks similar to Seegmiller et al. (2003) and Wei et al. (2018) during the VERT tasks. The first peak is described as the toe contact peak, and the second as the heel contact peak (Gross and Nelson, 1988; Seegmiller et al., 2003). Half of our participants could be missing the double peak because they only landed on their forefoot and forgone any heel contact. Alternatively, these subjects may only have a single peak because they landed more flat-footed. Our kinematic parameters indeed show that subjects are landing with less plantar flexion during the FLIP tasks. Although both FLIP and VERT tasks showed double peaks, the VERT double peaks are not nearly as dramatic as the FLIP. Specifically, subjects 1 and 5 show double peaks in close magnitudes. This behavior is not seen in the VERT task. Going off of the previous peak descriptions, the first peak in flip landings may be to decelerate high velocities at the foot and angular momentum of the body. Then, the purpose of the second peak may be to decelerate the COM in the vertical direction. Future research should consider the nature of these substantial double peaking during flip landing.

The current sagittal ankle angles at IC showed similar trends to Beatty and colleagues (2007), where the ankle was more plantar flexed during vertical tasks and more dorsiflexed during flipping tasks. However, they showed moderate dorsiflexion at IC during their back salto task, and our participants were still in slight plantar flexion. We also found significantly greater ankle plantar flexion moments during FLIP tasks. This difference is similar to Harty and colleagues (2011), who found significantly different sagittal ankle moments between three landing tasks.

It is also important to note that our sagittal ankle moments had a significant task and surface interaction, where the surfaces affected FLIP tasks more than VERT tasks. This observation may be related to the high loading parameters and downward foot orientation at IC (discussed in more detail later, see page 58) during FLIP task, and the compliant property of the MAT surface. High impact forces due to the FLIP angular velocity on a downward-oriented foot may have caused greater external dorsiflexion moments that the ankle would have to overcome. Then, landing on the MAT surface may have absorbed some of the impact energy during landing. This would explain why we observed lower internal ankle plantar flexion moments on the MAT surface compared to the HARD. Xiao and colleagues (2017) did not show much change in their ankle moment magnitudes when simulating flip landings on different mats. However, their simulations only altered mat stiffness, dampness, and friction properties and did not compare the effects of landing without a mat. This could be a situation where FLIP tasks benefit more from the MAT surface than the VERT tasks because of the vast differences in impact and loading between tasks. In this case, the cushioning properties of the MAT may have mitigated the amount of ankle effort required when compensating/absorbing the high impact and loading parameters during FLIP landing.

Additionally, the flipping orientation of the body may cause the toes to be pointed down towards the ground, regardless of plantar flexion angles. The GRF vector orientation on the downward foot could introduce greater external ankle dorsiflexion moments, which the ankle would have to counter with greater internal ankle plantar flexion moments. It is then possible that matted surfaces are a key component in modulating these high sagittal ankle moments during flip landings (Xiao et al., 2017). Although Xiao et al. (2017) did not show great increases in ankle plantar flexion torque when flips were simulated on stiffer surfaces, they did show that the time to peak ankle plantar flexion torque occurred earlier in the landing phase. This similar trend can be observed in our FLIP moment curves (Figure 6).

Unlike other studies, we did not observe any significant differences in ROM at the knee or ankle. Edwards and colleagues (2009) did not show any ROM differences between tasks, similarly to us. However, they compared two vertical tasks rather than a flip and a vertical task. Beatty and colleagues (2007) generally showed greater sagittal ROM in flip landing tasks compared to vertical landing tasks. McNitt-Gray and colleagues (1994) reported significantly higher sagittal ROM when landing with no mat compared to with a mat. Our participants may not have displayed differences in joint ROM because they are typically taught to land as aesthetically as possible, which may involve landing as upright as possible. While McNitt-Gray et al. (1994) reported greater joint ROM when their gymnasts landing on no mat, they also reported lower impact peaks and loading rates due to higher joint efforts to absorb impact. Our subjects may not have been trained to absorb impact using more joint effort between surfaces or tasks like those gymnasts. The lack of joint compensation may also explain why our impact peaks and loading rates were greater on the HARD surface compared to the MAT surface.

Joint positions at IC are one of the most critical factors and a primary determinant for injury occurrences at the ankle and knee (Wright et al., 2000; Laughlin et al., 2011). Greater ankle plantar flexion and inversion at IC is a considerable risk factor for ankle injuries (Wright et al., 2000; Mok et al., 2011; Tropp, 2012). We expected our participants to display greater plantar flexion at IC during the FLIP tasks compared to the VERT tasks. Cheerleading is judged on aesthetics, and pointed toes during airborne maneuvers are typically more pleasing and display better technique. Oppositely, we observed greater plantar flexion at IC during the VERT tasks compared to the FLIP tasks, like Beatty et al. (2007). It is possible plantar flexion was greater during the VERT task because our participants pointed their right foot further towards the ground as they lowered their COM and stepped off the platform. Choosing a more laid-out (straight body) flipping task could also impact plantar flexion since all body segments are extended during that maneuver. The task performed also affected frontal knee angles at IC. In this study, knee adduction at IC was greater during FLIP. Greater knee varus at IC has been associated with greater chances of knee injuries, including posterior cruciate ligament sprains and hamstring strains (Grieg, 2019; Wind et al., 2004). Although the tasks did not affect frontal ankle angles at IC, the surfaces did have a significant effect. Our participants showed greater ankle inversion at IC on the HARD surface. Joint positions at IC could change depending on which FLIP task is performed (e.g., laid-out flip with body in full extension vs. tucked flip with body in a flexed position). Additional research should further compare kinematic landing parameters of different flip tasks. Hip kinematics were also not included in this project, and they may be worth investigating in further studies.

Solely based on touchdown joint angles, the VERT tasks had a higher risk of ankle injuries while the FLIP tasks had a higher risk of knee injuries. However, it is also essential to consider the body orientation during back tuck flips. The body will likely be rotated slightly forwards as individuals approach landing. Therefore, the toes will likely be orientated towards the ground despite the relatively neutral ankle during FLIP tasks. This downward-toe position at IC may play as a huge contributor to ankle injury risk since a plantar flexed or toe-pointed position is a significant determinant of ankle sprains (Wright et al., 2000). Even though the VERT tasks had greater plantar flexion, it is still possible the FLIP tasks had IC kinematics that had a higher chance of ankle sprains due to the forward-rotated orientation of the body. Then, ankle injury risks are higher when landing on a harder surface, regardless of task. In general, individuals showed IC joint positions that increased the chances of injuries when performing FLIP tasks on a HARD surface. These risker IC positions included greater knee extension and adduction, greater ankle inversion, and a downwards-oriented foot.

Injury risks are not affected by joint kinematics alone. Rather, they also greatly depend on joint kinetics. Higher peak joint moments are generally associated with greater injury risks at the ankle and knee (Donnelly et al., 2017; Harty et al., 2011, Hong et al., 2014). Peak knee extension and ankle plantar flexion moments were greater during the FLIP task compared to the VERT task. The same relationship was seen for peak knee abduction and ankle eversion moments. We also observed significant surface effects on FLIP tasks. It is important to note that these ankle plantar flexion and eversion moments occur in response to externally applied dorsiflexion and inversion moments, and higher ankle plantar flexion moments are associated with greater injury risks (Hong et al., 2014; Donnelly et al., 2017). Therefore, the larger internal ankle plantar flexion and eversion moments during FLIP are signs of elevated ankle sprain risk. At the knee, abduction moments occur in response to external moments, causing the tendency for knee adduction, and greater knee extension and abduction moments are associated with greater ACL injury (Sigurðsson et al., 2021; Harty et al., 2011; Hong et al., 2014; Donnelly et al., 2017). Therefore, the larger internal knee extension and abduction moments during FLIP are signs of elevated ACL injury risk. Our study indicates that performing FLIP tasks places more active stress on the ankle and knee joint during landing and increases the risk of ankle and knee injuries compared to VERT tasks. Furthermore, performing FLIP tasks over a harder surface increases the risk of injury further. Hip moments were not analyzed in this study, but adding hip kinetics in further studies may tell a fuller story of joint efforts during FLIP and VERT landings.

The current data suggests FLIP tasks puts the ankle and knees at greater risk of injury. Although, the surfaces that participants performed landing tasks on did not seem to have any effect. This finding differs from Xiao and colleagues' (2017) flip-simulations that suggested stiffer surfaces may cause greater joint moments. The current joint moments may follow a somewhat similar trend to the loading rates, where the surface is more important for loading rates than the task. Here, the surface did affect the peak moment magnitudes as much as the task effect. Instead, the surface may have delayed the time onset of the peak moments. The moment curves show the tendency for the peak moments to occur earlier on the HARD surface compared to the MAT surface (Figure 5). Similar to this theory, Xiao and colleagues (2017) also reported that the time to peak joint moments increased when they simulated damper landing mats. Quicker onsets of internal joint moments may be crucial for resisting risky ankle motions, but peak moments that occur too quickly are also associated with greater injury risks (Nyland and Carbon, 2004; Rudolph et al., 2001). Although no significant surface effects were observed with joint moments, there was a significant task and surface interaction in the sagittal ankle moments. But as previously discussed, that may be more associated with FLIP tasks benefiting more from the cushion properties of the MAT.

While not the focus of this study, cheerleaders are unique from gymnasts because these athletes tumble with shoes. The shoes that cheerleaders practice and compete with, in theory, may affect landing parameters (Malisoux et al., 2017; Wei et al., 2018; DeBiasio et al., 2013; Wang et al., 2017). However, most previous studies focusing on shoes have examined rearfoot cushioning during running and landing activities. In the FLIP and VERT tasks, most of the impact phase occurs without the heel touching the ground. Given that the forefoot cushioning in cheerleading shoes is generally minimal, any benefits are likely small. Since cheerleaders typically perform on a cheerleading mat, there is a potential for shoe and surface interactions during flip landings. Malisoux and colleagues (2017) reported significant shoe material and surface cushioning interactions within loading rates during jump activities. However, the rotational component of flipping may alter or drastically change any potential interactions. For this study, we chose only to investigate the effects of tasks and cheerleading surfaces since cheerleading surfaces tend to be thicker than a shoe's midsole. It is also unclear what the extent of a cheerleading shoe's impact would be. Cheerleaders may not benefit from a heel-concentrated midsole, and a minimal cheerleading shoe may not have enough forefoot material to invoke much of an effect. Therefore, we believe these cheerleading surfaces may have more of an impact on landing parameters than shoes. Although, it goes without saying that further research is warranted for possible interactions between cheerleading shoes and surfaces.

As noted earlier, the main limitations of this study relate to matching VERT and FLIP landing heights. First, using the PSIS markers to estimate the COM trajectory was not a perfect estimation of the true COM flight height during FLIP tasks. We discovered after the study's completion that there was adequate data captured to identify the approximate instant of takeoff, and thereby an estimate of flight time. In future studies, this may be a better marker for matching flight height. However, we do believe using the PSIS marker trajectories was a reasonable approach for approximating flight height. Second, the height-adjustable platform we used for the VERT tasks did not have unlimited configurations, and we had to choose a height closest to the individual's vertical FLIP displacement. The differences between FLIP height and platform height were within a few centimeters, and we did not anticipate dramatic effects to landing parameters due to this limitation. Third, we noticed afterward that some participants would lower their COM prior to stepping off the platform during the VERT tasks. This appeared to cause discrepancies between the actual VERT and FLIP landing heights based on the vertical COM velocity at IC. These variables may contribute to lessening the comparison quality between out study's VERT and FLIP tasks, and those discrepancies are observable when we glance at the vertical foot velocity at impact. However, the bulk difference in the vertical foot velocities is due to the angular component of the FLIP task. The effect of angular momentum on the vertical foot velocity may then explain why impact parameters (e.g., impact peaks, loading rates, joint moments) are significantly greater during FLIP tasks compared to VERT tasks.

The primary purpose of this experiment was to compare landing parameters between flip and vertical landing tasks. This was to help explain the ecological validity of using vertical tasks to represent landing mechanics of acrobatic populations. We found impact velocities at the distal segments were significantly higher during FLIP tasks due to the body's angular velocity that the VERT task is missing. These larger impact velocities then caused greater initial loading (almost two times greater), which subsequently altered joint kinematics and kinetics. These results would indicate individuals should be cautious when using vertical landing tasks to summarize landing mechanics within acrobatic populations, as athletes within these groups typically perform flip landings. The next purpose was to compare the effects of different cheerleading surfaces on landing to investigate how impact parameters are modulated within the sport of cheerleading. We found having a compliant surface (or not having a compliant surface) does not affect impact peaks, but it did alter loading rates. Higher loading rates in the presence of a harder surface is indicative of greater injury risks. We also observed greater ankle inversion at IC on the HARD surface, which is highly associated with greater ankle injury risk. Overall, FLIP tasks are unique from VERT tasks because of the angular component. Then, flipping on a harder surface places athletes at risk for ankle injuries due to greater impact peaks and loading rates during FLIP tasks, greater loading rates on the HARD surface, riskier ankle inversion at IC, and greater joint stress. These results would suggest that using a cheerleading mat is essential for injury prevention, as landing on a mat in our study mitigated high forces and improper foot placement. Future work should emphasize refining flight height estimations for a closer comparison between flipping and vertical tasks. Our methods of approximation weren't perfect, but they were close and only off by only a few centimeters. Second, it may be worth comparing the effects of different flips on landing parameters. Flipping in a fully extended body position may place the ankle in riskier positions (more plantar flexed and inverted) at IC. Lastly, future research should investigate potential interactions of shoes and surfaces on flip landings, as cheerleaders uniquely wear shoes when tumbling compared to gymnasts.

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Appendix A:

Recruitment Flyer

CHEERLEADERS NEEDED FOR RESEARCH STUDY!

TITLE

The effects of cheerleading surfaces on landing characteristics during vertical and flip landings.

Purpose

We want to compare the effects of two cheerleading surfaces (hard vs. matted) between vertical drop landing and flip landing tasks.

Where will this take place?

UW-Milwaukee Enderis Hall – Room 132

Who can participate?

- Collegiate cheerleaders, ages 18-26
- Must have at least one prior year of cheerleading experience
- Must be able to perform A round-off, back tuck and provide video evidence of flipping abilities at the testing site
- Must not have had any lower extremity injuries within the last 6 months
- Must not have had any lower extremity surgeries ever
- Must not have any current condition that will interfere with the ability to perform flipping tasks
- Must not be pregnant

What does this study involve?

- One testing session (1 hour and 30 minutes)
    - Filling out a screening and subject information questionnaire Performing round-off, back tucks onto two different surfaces (cheerleading mat and bare floor) while landing on a force sensing surface
    - Performing vertical drop landing tasks onto two different surfaces (cheerleading mat and bare floor) while landing on a force sensing surface
    - Wearing special tracking markers while performing study tasks

INTERESTED IN PARTICIPATING
OR HAVE ANY QUESTIONS?
Contact Anthony Nguyen
Email: nguyenav@uwm.edu
Phone: 616-818-9916

APPENDIX B:

Recruitment Script

Hi, my name is Anthony, and I am a master's student in the Kinesiology program at UW-Milwaukee. I am conducting a research study examining landing mechanics within cheerleaders, and I'd like to welcome you to participate in the study. The goal of the study is to understand the loading on the legs when landing from a round-off, back tuck flip on a cheerleading mat and on a hard surface like a basketball court. I am looking for cheerleaders (any gender) with at least one-year of experience who are proficient at round-off, back tuck flips.

Participation in this study is voluntary and will only take about one hour and 30 minutes. During that time, you will be asked to perform round-off, back tuck flips while motion and force information are recorded. The goal is to record at least three successful landings where your foot lands on a force-sensing surface (with a maximum of 10 attempts). This will be done both with a cheerleading mat and again without the mat. Simple vertical landings from a platform will also be recorded for each surface.

If you are interested in participating, I will send you an eligibility screening questionnaire. Then, an email will be sent later informing you if you are an eligible candidate or not. To be eligible, you must have at least one year of cheerleading experience, have been on a cheerleading team for at least the past 6 months, be able to demonstrate proficiency in performing the task, not have any lower extremity surgeries or recent injuries, and not be pregnant.

There will be no direct benefit to you or any subject compensation. However, your participation will benefit society by furthering the scientific literature on the under-represented sport of cheerleading. The overall results will also be shared to you once the study has been completed.

If you have questions or would like to participate, please email me (nguyenav@uwm.edu), and I will be more than happy to provide further details.

APPENDIX C:

Screening Questionnaire

1. What is your name?
2. Please provide a contact email.
3. Are you between the ages of 18 and 26?
4. Are you currently active with a collegiate cheerleading team or have been active with a collegiate cheerleading team within the last 6 months?
5. How many years of cheerleading experience do you have?
6. Are you able to perform a round-off, back tuck flip?
7. Are you pregnant?
8. Have you had any lower extremity injuries within the last 6 months? If so, please provide further details.
9. Have you ever had any lower extremity surgeries? If so, please provide further details.
10. Do you have a current condition(s) that prevents/interferes with your ability to perform flipping or landing tasks (e.g., stepping off of a stool and landing on the ground with both feet)? If so, please provide further details.
11. Do you have adequate video evidence of your ability to perform a round-off, back tuck or a similar or more advanced skill? If not, can you acquire adequate video evidence of your ability to perform a round-off, back tuck or a similar or more advanced skill? (Providing video evidence on the day of data collection will be extremely crucial for the continuation of participation)

APPENDIX D:

Consent Form

Study title	The effects of cheerleading surfaces on landing characteristics during vertical and flip landings
Researcher	Anthony Nguyen, B.S., Master's student in the Department of Kinesiology

We're inviting you to participate in a research study. Participation is completely voluntary. If you agree to participate now, you can always change your mind later. There are no negative consequences, whatever you decide.

What is the purpose of this study?
We want to compare the effects of two cheerleading surfaces (hard vs. matted) between vertical drop landing and flip landing tasks.

What will I do?
Before coming in:

- You'll complete a screening questionnaire to determine your eligibility for this study. (5 minutes)
- We'll ask you to gather video evidence of your flipping abilities to show us when you come into the lab (1 minutes)
- We will ask you to wear/bring your cheerleading shoes and as minimal sports clothing as you are comfortable with for data collection (e.g., sports bra, spandex, tank top, running shorts) (2 minutes)

In our lab:

- You'll will be walked through the informed consent process, complete a questionnaire about your yourself, and have your height and weight measured (5 minutes)
- You'll be asked to warm-up by jogging, stretching, doing jumping jacks, etc. (10 minutes)
- You'll be asked to perform 3-5 practice round-off, back tucks (the flipping task) (5 minutes)
- We will place reflective markers on your skin and shoes. Markers will be placed on the lower back, hips, and right thigh, knee, shin, ankle, and shoe. (10 minutes)
- You'll be asked to perform the flipping task on top of a cheerleading mat while landing on a force sensing surface. Three successful trials are needed. A limit of 10 attempts will be placed. (20 minutes)
- You'll be asked to drop from a platform that will match your flip landing height while landing on a force sensing surface. This will be done on the same cheerleading mat. Three successful trials are needed. A limit of 10 attempts will be placed. (10 minutes).
- You will be asked to perform the flipping and drop landing tasks again without the presence of a cheerleading mat. Three success trials are needed for each task. A limit of 10 attempts will be placed for each task. (30 minutes).
- You can be withdrawn if your flipping performance during the study does not match the skill level from your provided video.

Risks

Possible risks	**How we're minimizing these risks**
Breach of confidentiality (your data being seen by someone who shouldn't have access to it)	• All identifying information is removed and replaced with a study ID. • We'll store all electronic data on a password-protected, encrypted computer. • We'll store all paper data in a locked filing cabinet in a locked office.
Minor muscle soreness, muscle strain, or ligament strain (Unlikely)	• We will not ask you to perform activities beyond your typical practice. Intensity and volume of activities will also not exceed your typical practice. • Practice trials will be performed to allow you to become familiar with the protocol • Adequate and frequent rest periods will be given. • We'll provide first-aid medical treatment in the unlikely event of physical injury • Students will be referred to the Norris Health Center for follow-up care. Non-UWM students will be referred to their primary care physician and will be responsible for all expenses incurred.
Minor skin irritation from the reflective marker adhesives (Unlikely)	• If you feel any irritation while participating, please tell the investigators as soon as possible • Students will be referred to the Norris Health Center for follow-up care. Non-UWM students will be referred to their primary care physician and will be responsible for all expenses incurred.

There may be risks we don't know about yet. Throughout the study, we'll tell you if we learn anything that might affect your decision to participate.

What if I am harmed because I was in this study?

If you're harmed from being in this study, let us know. If it's an emergency, get help from 911 or your doctor right away and tell us afterward. We can help you find resources if you need psychological help. You or your insurance will have to pay for all costs of any treatment you may need.

Other Study Information

Possible benefits	• The cheerleading population may benefit from more research on injury risk parameters within their sport. • This study may guide and refine the methods of other landing studies • You may feel satisfaction or fulfillment from contributing to research in your sport.
Estimated number of participants	12 collegiate cheerleaders (male and female; ages 18-26)

How long will it take?	One hour and 30 minutes
Costs	On campus parking
Compensation	No subject compensation will be given.
If I don't want to be in this study, are there other options?	No.
Future research	Your data won't be used or shared for any future research studies.

Data Security

What identifying information will be collected and why?	Your name and email address will be collected in order to share overall results when the study is completed.
How long will my data be kept?	Until August 31st, 2023
How is data kept secure?	• Screening questionnaire data will be stored on a password protected account. Electronic data will be stored on a desktop computer in END 132, which will be password protected. Data collected on paper will be stored in a file cabinet in END 132, which will be locked.

Who might see my data and why?

The researchers	To conduct the study and analyze the data
The IRB (Institutional Review Board) at UWM The Office for Human Research Protections (OHRP) or other federal agencies	To ensure we're following laws and ethical guidelines
Anyone (public)	We plan to share our findings in publications or presentations. You will not be identified by name.

Contact information:

For questions about the research, problems, or complaints	PI: Dr. Kristian O'Connor SPI: Anthony Nguyen	414-251-5277 / krisocon@uwm.edu 616-818-9916 / nguyenav@uwm.edu
For questions about your rights as a research participant, problems, or complaints	IRB (Institutional Review Board; provides ethics oversight)	414-662-3544 / irbinfo@uwm.edu

Signatures

If you have had all your questions answered and would like to participate in this study, sign on the lines below. Remember, your participation is completely voluntary, and you're free to withdraw from the study at any time.

____

Name of Participant (print)

Signature of Participant Date

Name of Researcher obtaining consent (print)

Signature of Researcher obtaining consent Date

Remember, your participation is completely voluntary, and you're free to withdraw from the study at any time. Do you have any questions about the study? Do you agree to participate?

APPENDIX E:

Demographic, Injury History & Cheerleading Skill Level Questionnaire

For the Investigator:
Adequate Skill Level Verification
Did the subject procure adequate video evidence of their ability to perform a round-off, back tack or a similar or more advanced skill? ☐Yes ☐No
If not, the participant cannot continue with the study.

For the Participant:
Demographic, Injury & Physical Activity Questionnaire
Please answer the following questions to the best of your ability.

Age: _______

Gender: _________

Height: _________

Weight: _________

How many years of cheerleading experience do you have? ________

How long have you been on a collegiate cheerleading team? ________

Please list your position(s) on your cheerleading team: (e.g., flyer, base, tumbler, etc.)
____
____
____

Have you ever sprained your ankle? If so, how long ago and what were you doing when it happened?
____
____
____

Comments/Notes:
____
____
____