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Angular Kinematics Study on Parachute Landing Activity for Professional and Amateur Parachutists of Malaysian Military Using Video Processing Technique

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ABSTRACT

This study focusses on the angular kinematics analysis, namely angular displacement, angular velocity, and angular acceleration among professional and amateur paratroopers of Malaysian military using video processing technique. They are three professional and eighteen amateur parachutists who are Malaysian army participated in this study. The video data was captured based on the event "before their foot touched the ground" using three GoPro cameras at 60 fps (frame per second). The angular kinematics data has been analysed using the Quintic Biomechanics Software v26. The study of angular kinematics can help to find the optimum flexion angle and the angular displacement for the hip, knee and ankle joint during landing. The results showed that professional parachutists bent their hip and knee and flexed the balls of their feet more during landing. This produced change in angular displacement, angular velocity and angular acceleration.The optimum angular displacement are 1.31 *rad* (hip flexion), 0.79 *rad* (knee flexion) and 0.94 *rad* (ankle flexion). The optimum angular velocity are 0.03 $rads^{-1}$ (hip flexion), 0.27 $rads^{-1}$ (knee flexion) and -4.19 $rads^{-1}$ (ankle flexion). The optimum angular acceleration are -35.17 $rads^{-2}$ (hip flexion), 55.26 $rads^{-2}$ (knee flexion) and -22.33 $rads^{-2}$ (ankle flexion). The optimum angular kinematics parameters can be served as guidelines and reference for the amateur parachutists to perform the optimum landing and minimise the injury.

Keywords: Angular kinematics data, PLF technique, injury.

1. Introduction

The sovereignty of a nation depends on the security and strength of the armed forces of each state. The selection of soldiers must adhere to the perfect physical specifications and good health conditions as they must withstand all the necessary military training. Military physical exercises such as war exercise, abseiling and rappelling are among the risky activities that may cause injury to the army. This is followed by the failure to control the parachute and negligence in the use of weapons and explosives (Chervak et al., 2010). In Malaysia, the paratroopers are known as the 10 Brigade Paratroopers and started operations in 1970. The 10 Para Brigades are elite parachute teams standing with parachutes abroad, such as the United States Delta Force. In addition, the speed and the efficiency of the elite unit of 10 Para Brigades have been a major advantage to the Malaysian Armed Forces (ATM) in carrying out its mission to ensure that the country's security is maintained.

Parachute landing fall (PLF) is a technique used by the Malaysian armed forces for parachuting landing activities, even the US military used the same technique. Besides, there is another technique used by the troops in Russia and China for the parachute landing activity and it is known as Half-Squat Parachute Landing (Niu et al., 2010). The difference between the PLF technique and the HSPL is that the PLF has two phases, namely the elbow and knee flexion as the foot touched to the ground and rolls. While HSPL is just involving knee, ankle and forefeet being put together with the plantar is parallel to the ground. Based on this study, the PLF technique is more effective because during the rolling phase it can lessen the high impulse force to the ankle.

In biomechanical explanation, the ankle is the highest probability of getting injury during landing activity (Bricknell and Craig, 1998, Knapik et al., 2010, Neves et al., 2009, Whitting et al., 2009). The ankle is the first joint that contact with the ground and receive the impact force from full-body (Whitting et al., 2009). Anterior Cruciate Ligament is the common injury to the ankle if the landing technique of the parachutist is not optimum. The optimum landing technique that can reduce injury is the ankle flexion must be less than 45° and landing using the balls of their feet. In addition, Knapik et al. (2010) the ankle injuries, ankle sprains, and ankle fractures can be avoided by using ankle brace during the military parachuting. The knee is also the joint that has a higher chance of getting an injury during landing. Several studies showed that the low knee flexion (less than 30°) or higher knee flexion (exceed 130°) during landing can cause the ACL strain injury (Bern et al., 1992, Boden et al., 2000, Kiapour et al., 2013, Kim et al., 2015, Wu et al., 2018, 2010). In addition, the knee joint compressive force by ground impact can lead to anterior tibial translation when the knee is in full extension. The increase of knee flexion during landing can reduce the ground reaction force. A study in Wu et al. (2018) showed that the use of knee brace during HSPL activity can avoid injury and can protect knees from the extortion. In addition, hip flexion also plays an important role when performing the optimum landing. The extended and decreased hip flexion during landing activity increased the risk of antagonistic forces on the knee (Hashemi et al., 2011, Kipp et al., 2011, Pollard et al., 2010, Shultz et al., 2009, Yu et al., 2006). The hip flexion will cause the musculature surrounding the knee produces a posterior tibial force, but it was overextended or decreased and it will strain the ACL (Boden et al., 2000).

There are several researchers who studied on kinematics data during landing on the lower limb (Chappell et al., 2005, Chappell and Limpisvasti, 2008, Decker et al., 2003, Huston et al., 2001, Kwok et al., 2003, Shultz et al., 2009), as lower extremity has the highest record of injury for landing activity According to Ball et al. (2014) who have done a research about the record of injury during parachute landing, it is shown that out of 110 patients 65% have lower extremity injury followed by 22% neck or back injuries, 22% head injuries, and 19% have upper extremity injuries. Some researchers also studied about kinematics data on the upper limb but most of them focused more on the daily routine movement and for the stroke patients (Abidin et al., 2018, Ariffin and Rambely, 2016, Ponvel et al., 2019, Ramlee and Gan, 2017). Previous study, as reported in Aziz et al. (2019) was the comparison of kinematics data between professional and amateur parachutists on the whole body segments (wrist joint, elbow joint, shoulder joint, hip joint, knee joint and ankle joint). The kinematic parameters that have been studied were the linear velocity, acceleration and angle. Based on the result, it showed that the kinematic data from upper extremity has no significant difference between professionals and amateurs before foot touched the ground. As such, it is suggested that the angular kinematics of lower extremity which starts from the hip, knee and ankle joint may contribute to the parachute landing activity.

The main purpose of this study is to analyse and identify the angular kinematics parameters that contribute to the parachute landing activity among professional and amateur parachutists using video processing techniques. The data was collected based on the event "before feet touched the ground" as this study is aimed to recognize the optimum position of each body segment (lower extremity) during landing activity. In addition, these kinematics data from the professionals can be served as the reference for the amateurs to perform the optimum landing and avoid the injury.

2. Methodology

Three professional parachutists (age, 28 ± 1.73 yr; height, 1.67 ± 0.02 m; weight, 65.3 ± 7.6 kg) and eighteen amateur paratroopers (age, 23.8 ± 2.1 yr; height,1.69 ± 0.05 m; weight, 62.9 ± 5.9 kg)who are military army participated in this study. According to the parachute trainer, Mejar Ahmad Muadz a 1000-feet professional static parachute must make the jump more than 50 times. After that, the professional parachutist can proceed to free-fall parachute training with the height of 10,000 feet. In this experiment, the professional subjects had achieved 53 jumps meanwhile the amateurs were chosen from the military was following static parachute training and have never made any jump before. All the subjects have signed written consent before conducting this experiment. The ethical committee approval was obtained from the university in accordance with the Hospital Canselor Tuanku Muhriz (HCTM) guidelines.

During the 4 weeks training, all the participants followed the protocol as they have to wear the camouflage military uniform, boot and helmet that are specially designed for the paratroopers. In addition, during the experiment, all the subjects have to carry 10kg weight bag that placed in front of the body as the preparation as during the real jump, they have to carry more than 40kg load. The experiment begins when the subject clings into the iron swing, then another subject will push until they swing like a pendulum. After about 3 times swing the subject will release the iron swing and land by applying the

PLF technique. All subjects will make this behaviour for three times to perform the better result of kinematics data.

The parachute landing activities motion were recorded using three GO-Pro Hero 4 cameras with 60 frames per second (fps) and 1080 pixels of resolution. Figure 1 (left) shows the position of each camera during the experiment. Camera 1 is on the right of the subject to capture the sagittal plane. The position of camera 2 was on the back of the subject and the position of camera 3 has been adjusted 60° with the camera 1. All the cameras have been synchronized and connected with the Bluetooth so that all cameras can be started and stopped at the same timing. Figure 1 (right) shows the sagittal plane of the subject during parachute landing and angular kinematics parameters extraction is based on this plane. Meanwhile, Figure 2 represents the digitized process using Quintic Biomechanics Sofware v26 to produce the angular kinematics data. This study only focused on angular kinematics analysis on the sagittal plane in lower extremity. The calibration process has been done using a one-meter ruler as a benchmark to calculate the speed of video which was 59.4 per second. Subsequently, the video data were smoothened using Butterworth digital filter with a cut-off frequency of 3 Hz. As both groups have different numbers of data size. $T-$welch $t-$test has been chosen to be analyse the angular kinematics parameters with $p \leq 0.05$ and the 95% confidence interval. Figure 3 represented the flow chart of the methodology to produce angular kinematics data.

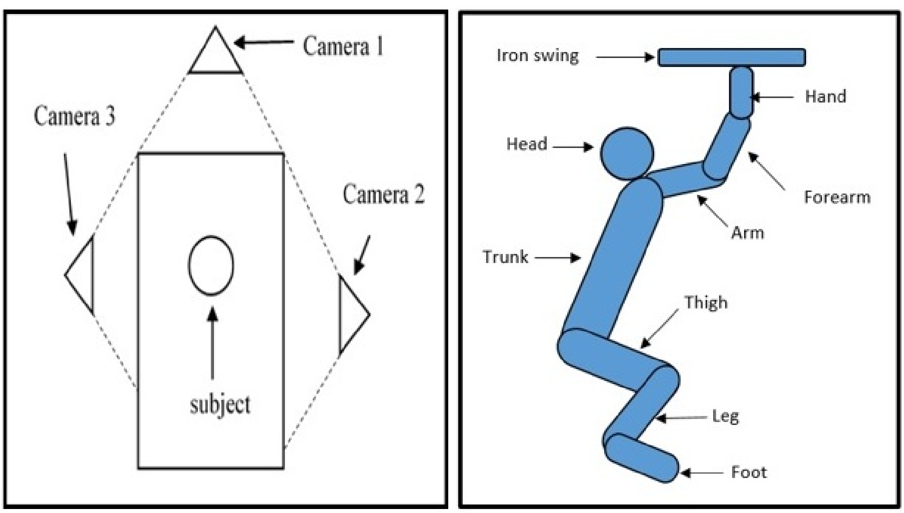


Figure 1: Left: Position of cameras and subject from the top view; Right: Position of the subject on the sagittal plane.

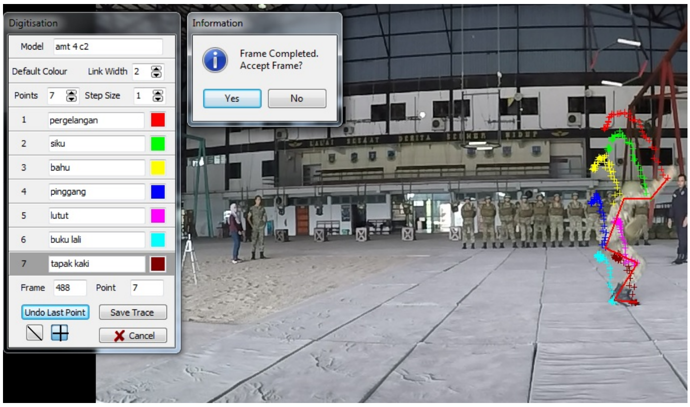


Figure 2: Digitize process using Quintic Biomechanics Software.

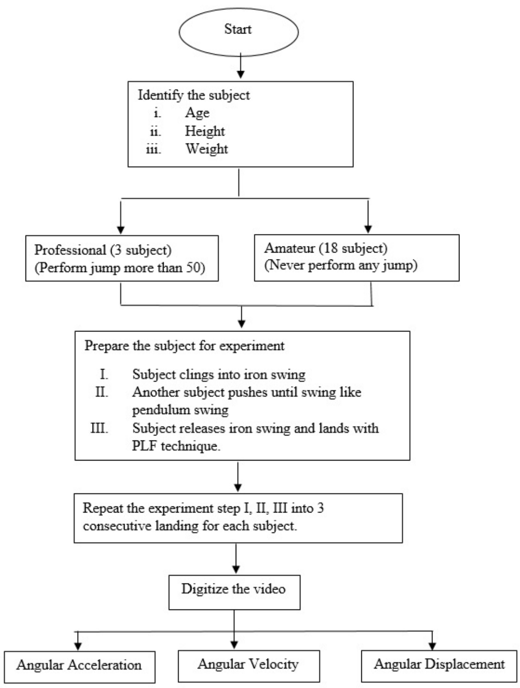


Figure 3: Flow chart of the methodology to produce angular kinematics data.

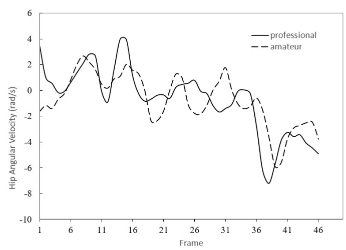
3. Result

The statistics test showed that there is a significant difference of hip, knee and ankle angular velocity between professional and amateur parachutists with ($p \leq 0.05$). Based on Table 1, the maximum value of the angular velocity at hip, knee and ankle joint from professionals data was lesser compared to the amateurs. The angular acceleration at the hip, knee and ankle joint has shown a significant difference ($p \leq 0.05$), between professionals and amateurs data. The maximum value for angular acceleration at hip, knee and ankle also showed that the amateurs accelerated in the angular motion more compared to the professionals. The difference is obvious at the angular acceleration of ankle joint that reached 15.85 rad/s^2 for professionals but recorded at 67.51 rad/s^2 for amateurs. In addition, the angular displacement at hip, knee and ankle joint also showed a significant difference between professionals and amateurs ($p \leq 0.05$). The value of maximum and minimum for angular displacement form amateurs was larger than professionals, thus showed that amateurs had less bending at their hip and knee during landing.

Figures 4, 5 and 6 represented the graph of value angular velocity, angular acceleration and angular displacement at hip, knee and ankle joint between the professional and amateur parachutists movement start from hanging into iron bar until foot touched the ground. Based on Figure 4 illustrate that the reading of angular velocity from amateurs data was higher than professionals especially at ankle joint. In addition, according to Figure 5 showed the angular acceleration for the professionals at knee and ankle joint was negative value after frame 21 (feet touched the ground). It can be concluded that the movement at knee and ankle joint for professionals was slowing down. Furthermore, Figure 6 was also showed that the angular displacement at the hip, knee, and ankle joint for the professionals was lesser than amateur parachutists.

Table 1: The mean, maximum and minimum value of event during subject before feet touch ground between professional and amateur parachutist.

	Professional			Amateur		
Variable	Mean	Max	Min	Mean	Max	Min
Angular Velocity (rad/s)						
Hip flexion	0.03	2.00	-2.25	-1.24	3.48	-6.75
Knee flexion	0.27	3.24	-1.92	1.05	7.70	-5.54
Ankle flexion	-4.19	-0.01	-9.29	-5.02	2.72	-14.63
Angular Acceleration (rad/s^2)						
Hip flexion	-35.17	37.5	-118.63	-38.55	5.093	-126.88
Knee flexion	55.26	142.33	-9.05	63.06	180.41	-28.08
Ankle flexion	-22.33	15.85	-80.48	-18.57	67.51	-167.19
Angular Displacement (rad)						
Hip flexion	1.31	2.01	1.93	2.26	2.57	1.92
Knee flexion	0.79	1.81	0.75	2.03	2.35	1.55
Ankle flexion	0.94	1.19	0.62	1.42	1.91	0.84



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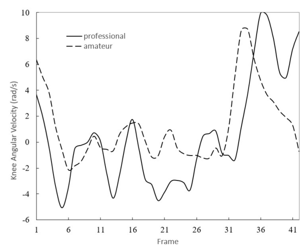

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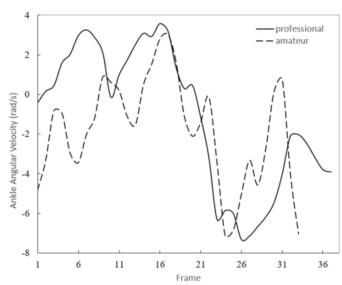
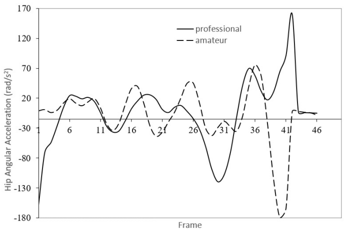


(c)

Figure 4: Angular Velocity between professionals and amateurs (a) hip (b) knee (c) ankle



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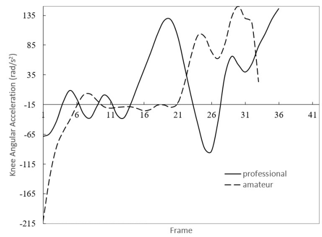

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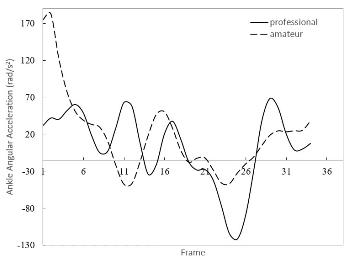
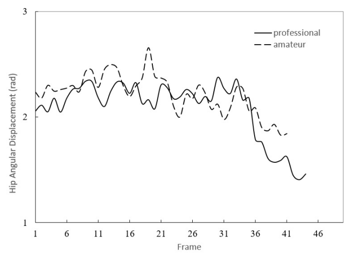


(c)

Figure 5: Angular Acceleration between professionals and amateurs (a) hip (b) knee (c) ankle



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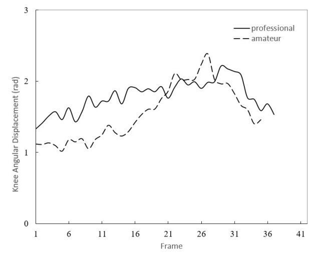

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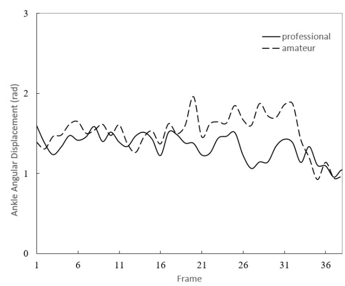

(c)

Figure 6: Angular Displacement between professionals and amateurs (a) hip (b) knee (c) ankle

4. Discussion

The optimum landing during parachute activity is the important thing to know for all the parachutists to perform better landing without any injury. This study focused specifically on the event "before feet touched the ground" to see whether or not the amateurs apply the correct PLF technique during landing. The value of angular velocity was taken to observe the change of angular position or orientation for the hip, knee and ankle joint with time. Meanwhile, the angular acceleration was recorded to define the rate of changes of angular velocity. The value of angular velocity was taken to observed changed of the angular position or orientation for the hip, knee and ankle joint with time. Meanwhile, the angular acceleration was recorded to define the rate of changes of angular velocity. The value of angular velocity and acceleration have positive and negative value because it follows the movement of the joint and the increasing or decreasing of angular displacement. Based on Table 1, it can be seen that the maximum value for angular velocity, angular acceleration and angular displacement for the professional parachutists are much lesser compared to the amateur parachutists.

The analysis showed that the flexion of the hip joint plays an important role to perform a better landing. According to Kiapour et al. (2013) the ACL injury will occur if the hip flexion was exceeding more than 130° (2.26 *rad*) or less than 30° (0.524 *rad*). Based on Table 1, it shows that the mean and the maximum angular displacement of the hip flexion for the professional parachutists were 1.89 *rad* and 2.01 *rad*, meanwhile for the amateur were 2.26 *rad* and 2.57 *rad*. Based on the amateurs result, it will cause injury because they landed with erected posture. Hip was the location of the body's center of mass during the landing phase, therefore the flexion of the hip and the orientation of the trunk are the important factors that contribute to ACL injury risk. According to Shultz et al. (2009) the erect posture at the trunk may be dangerous to the knee but it can be avoided by flexing the trunk as it will allow the increase protective hamstring muscle activation. Moreover, the hip flexion also gave influence to the ground impact force whereas it allows for muscle associated with the knee joint to better absorb landing impact force and other rotational torque (Kipp et al., 2011).

The knee joint has a high risk for injury during parachute landing activity. According to Wu et al. (2018) the most common injury is a fracture of the knee joint followed by injuries of the cruciate ligaments, collateral ligaments, and meniscus. In biomechanics study, some researchers (Bern et al., 1992, Boden et al., 2000, Hashemi et al., 2011, Kim et al., 2015, Wu et al., 2018, 2010) found that a low knee flexion angle which is less than 30° or exceed 130° for the landing activity will cause the ACL and injury. Based on Table 1, it shows that the knee flexion of angular displacement for the professionals was only 1.81 *rad* (103.7°) meanwhile the amateurs reached 2.35 *rad* (134.7°). According to the result, it shows that the position of knee flexion from amateur parachutists will cause the ACL injury. The low knee flexion will also cause limitation to the protective effects of hamstring co-contraction (Boden et al., 2000). Moreover, other biomechanics study found that the knee injury occurs especially during the impact force and will cause injury at the meniscus and articular cartilage (Kiapour et al., 2013). The anterior cruciate and collateral ligaments were at a higher risk of tear during the peak knee flexion angle. Therefore Wu et al. (2018) has suggested that wearing the knee braces for all the military paratroopers is needed to avoid knee injury.

In biomechanics study, it is found that the ankle is the joint that has the highest percentage of injury for the landing activity. Based on the research done by Ellitsgaard (1987) the collection of injury data from 110,000 sports jumps found that injury at lower extremity was 59.7% whereas 25% was the ankle fracture. The ankle was easily injured because it is the first joint to suffer impact from the ground and receives force from the full-body (Neves et al., 2009). The ankle flexion of angular displacement, angular velocity and angular acceleration could reduce the dangerous joint compressive force at the knee (Hashemi et al., 2011) and also affect the reading ground reaction forces. Some researchers found that landing with the flat-footed has a potential risk to ACL rupture since it generated a higher value of ground reaction forces (Boden et al., 2000). Landing with the toe first will be extending the knee and plantar flexed the feet more at the initial ground contact and may lead to a reduction in quadriceps activation (Shimokochi et al., 2009). Based on Figure 6 and Table 1 the ankle flexion from professionals is much lesser compared to the amateur parachutists.

This research analysed the difference of angular kinematics data from professional and amateur parachutists based on the event "before feet touched the ground" at the sagittal plane. The angular kinematics data from professional parachutists can be served as a reference for the amateurs to produce the optimum landing and avoid injury.

5. Conclusion

This study showed the comparison of angular kinematic data between professional and amateur parachutists during before the feet touched the ground. The result from the professionals data can be used as a reference for an amateurs parachutist who has never experienced a parachute landing to perform the better landing and avoid injury. This study also showed that the professional parachutists produced lesser angular velocity, angular acceleration and angular displacement at hip, knee and ankles. From the results, it can be concluded that professional parachutists bent their hip, produced more knee and ankle flexion. The limitation of this study is that all the subjects wore camouflage military uniform and boot during the training and the experiment need to be conducted using markerless motion video recording. However, this study design can produce data similar to the real training of parachute landing since all the subjects wore the same outfit. In addition, the limitation speed of the camera produced a small number of frames for each movement. Further research will discuss the kinetics data, which is torque by applying the mathematical model using Kane's method. Since it demonstrates high knee valgus and value of torque during landing jumping activity will cause the ACL injury.

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References

Abidin, S. B. Z., Jusoh, W. N. I. W., and Beng, G. K. (2018). Kinematic analysis on reaching activity for hemiparetic stroke subjects using simplified video processing method. *Malaysian Journal of Fundamental and Applied Sciences*, 14(3):386–390.

Ariffin, M. S. and Rambely, A. S. (2016). Optimization of upper extremity muscles using compound bow via lagrange multiplier method (lmm). In *AIP Conference Proceedings*, volume 1750, pages 30030–30037. AIP Publishing.

Aziz, S., Rambely, A., and Rauf, U. (2019). Kinematics study on plf technique by comparing professional and amateur Malaysian army parachutists based on event during landing. In *Journal of Physics: Conference Series*, volume 1366, pages 12054–12064. IOP Publishing.

Ball, V. L., Sutton, J. A., Aicha Hull, A., and Sinnott, B. A. (2014). Traumatic injury patterns associated with static line parachuting. *Wilderness and Environmental Medicine*, 25:89–93.

Bern, G., Hull, M., and Patterson, H. (1992). Strain in the anteromedial bundle of the anterior cruciate ligament under combination loading. *Journal of Orthopaedic Research*, 10:167–176.

Boden, B., Dean, G., Feagin Jr, J., and Garrett Jr, W. (2000). Mechanism of anterior cruciate ligament injury. *Orthopedics*, 23:573–578.

Bricknell, M. C. M. and Craig, S. C. (1998). Military parachuting injuries: a literature review. *Occupational Medicine*, 49(1):17–26.

Chappell, J., Herman, D., Knight, B., Kirkendall, D., Garrett, W., and Yu, B. (2005). Effect of fatigue on knee kinetics and kinematics in stop-jump task. *American Orthopaedic Society for Sports Medicine*, 33(7):1022–1029.

Chappell, J. and Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *American Orthopaedic Society for Sports Medicine*, 36(6):1081–1086.

Chervak, M. C., Hooper, T., Brennan, F. H., Craigh, S. C., Girasek, D. C., Schaefer, R. A., Barbour, G., Ywe, K. S., and Jones, B. H. (2010). A systematic process to prioritize prevention activities sustaining progress toward the reduction of military injuries. *American Journal of Preventive Medicine*, 38(1):11–18.

Decker, M., Torry, M. R., Wyland, D., Sterett, W. I., and Steadman, J. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics*, 18:662–669.

Ellitsgaard, N. (1987). Parachuting injuries: A study of 110,000 sports jumps. *Injury*, 21(1):13–17.

Hashemi, J., Breighner, R., Chandrashekar, N., Hardy, D. M., Chaudhari, A. M., Shultz, S. J., Slauterbeck, J. R., and Beynnon, B. D. (2011). Hip extension, knee flexion paradox: a new mechanism for non-contact acl injury. *Journal of Biomechanics*, 44(4):577–585.

Huston, L., Vibert, B., Ashton-Miller, J., and Wojtys, E. (2001). Gender differences in knee angle when landing from a drop-jump. *The American Journal of Knee Surgery*, 14(4):215–220.

Kiapour, A., Kiapour, A. M., Kaul, V., Quatman, C. E., and Wordeman, S. C. (2013). Finite element model of the knee for investigation of injury mechanisms: development and validation. *Journal Biomechanical Engineering*, 136(1):11002–11016.

Kim, S. Y., Spritzer, C. E., Utturkar, G. M., Toth, A. P., Garrett, W. E., and DeFrate, L. E. (2015). Knee kinematics during noncontact anterior cruciate ligament injury as determined from bone bruise location. *American Journal of Sport Medicine*, 43(10):2515–2521.

Kipp, K., McLean, S. G., and Palmieri-Smith, R. M. (2011). Patterns of hip flexion motion predict frontal and transverse plane knee torques during a single-leg land-and-cut maneuver. *Clinical Biomechanics*, 26(5):504–508.

Knapik, J. J., Spiess, A., Swedler, D. I., Grier, T. L., Darakjy, S., and Jones, B. (2010). Systematic review of the parachute ankle brace injury risk reduction and cost effectiveness. *American Journal of Preventive Medicine*, 38(1):182–188.

Kwok, P., Kong, W., Kasturi, K., Lee, C., and Hamilll, J. (2003). A biomechanical study on the parachute landing fall. In *17th AIAA Aerodynamic Decelerator System Techonology Conference and Seminar*, pages 2149–2158. American Institute of Aeronautics and Astronautics.

Neves, E., Souza, M., and Almeida, R. (2009). Military parachuting injuries in Brazil. *Injury*, 40(1):897–900.

Niu, W., Wang, Y., He, Y., Fan, Y., and Zhao, Q. (2010). Biomechanical gender differences of the ankle joint during simulated half-squat parachute landing. *Aviation, Space, and Environmental Medicine*, 81(8):761–767.

Pollard, C. D., Sigward, S. M., and Powers, C. M. (2010). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clinical Biomechanics*, 25(2):142–146.

Ponvel, P., Singh, D. K. A., Beng, G. K., and Chai, S. C. (2019). Factors affecting upper extremity kinematics in healthy adults: a systematic review. *Critical Reviews in Physical and Rehabilitation Medicine*, 31(2):101–123.

Ramlee, M. H. and Gan, K. B. (2017). Function and biomechanics of upper limb in post-stroke patients–a systematic review. *Journal of Mechanics in Medicine and Biology*, 17(06):1750099–1750118.

Shimokochi, Y., Yong Lee, S., Shultz, S. J., and Schmitz, R. J. (2009). The relationships among sagittal-plane lower extremity moments: implications for landing strategy in anterior cruciate ligament injury prevention. *Journal of Athletic Training*, 44(1):33–38.

Shultz, S. J., Nguyen, A.-D., Leonard, M. D., and Schmitz, R. J. (2009). Thigh strength and activation as predictors of knee biomechanics during a drop jump task. *Medicine and Science in Sports and Exercise*, 41(4):857–866.

Whitting, J., Steele, J., Jaffrey, M., and Munro, B. (2009). Does foot pitch affect parachute landing technique. *Military Medicine*, 174:832–837.

Wu, D., Zheng, C., Wu, J., Wang, L., Wei, X., and Wang, L. (2018). Protective knee braces and the biomechanics of the half-squat parachute landing. *Aerospace Medicine and Human Performance*, 89(1):26–31.

Wu, J.-L., Hosseini, A., Kozanek, M., Gadikota, H. R., Gill IV, T. J., and Li, G. (2010). Kinematics of the anterior cruciate ligament during gait. *American Journal of Sport Medicine*, 38(7):1475–1482.

Yu, B., Lin, C.-F., and Garrett, W. E. (2006). Lower extremity biomechanics during the landing of a stop-jump task. *Clinical Biomechanics*, 21(3):297–305.