Kinematics study on PLF technique by comparing professional and amateur Malaysian army parachutists based on event during landing

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Abstract. The paper discusses the difference of kinematics data for Parachute Landing Fall (PLF) technique on sagittal plane based on skill and experienced by comparing data between professional and amateur paratroopers during landing. Two events were accounted for this paper which is the “release the iron swing” and “before foot touch the ground”. Data were obtained by observing three professional and eighteen amateur paratroopers during three consecutive landings using motion caption analysis by Quintic Biomechanics Software. Professionals parachutists demonstrated a greater angle of body bending during landing and utilized smaller values of acceleration, velocity and angle joints during PLF technique for wrist, elbow, shoulder, hip, knee and ankle joints compared to amateur parachutists. The values of velocity, acceleration and angle in each joint from professionals can be used as a main reference for amateurs to perform parachuting training and reduce injuries.

1. Introduction
Military is a work that is very synonymous with rugged and dangerous activities. Among the activities carried out by the military are physical training (war exercises, abseiling and rappelling training), parachutes landing, shooting and explosives and weapons handling. According to [1] the highest military injury is due to physical training and this is followed by parachute landing and negligence in the handling weapons and explosive. This study will focus on the serious injuries experienced by soldiers who carry out parachute jumping and landing activities that can lead to death.

10 Brigade Paratrooper or known as 10 Para is special paratroopers unis for the ATM (Angkatan Tentera Malaysia). The team was established in 1970 as one of the modernization plans for the Malaysian military system. Participants selected to follow parachute training, must consist of soldiers with good physical health and achieved the standard body mass index. All the participant must pass three phases during four weeks training. The first phase is to apply PLF technique correctly, to land with emergency procedures if the main chute does not deploy or does not open correctly and learn how to land on water. For the second phase, all the participants will start to do training jump from the high
tower with the height of 32 feet. For the last phase, all the participants will execute the jump 8 times with at least two jumps in full battle equipment from the height 1000ft. The parachutist will be classified as a professional when successfully jumping 50 times without injury for the static umbrella.

There are two types of jumps used by the army namely "Parachute Landing Fall" (PLF) and also "Half-Squat Parachute Landing" (HSPL). Countries that use PLF techniques for parachute military training sessions are Malaysia and the United States, while HSPL jump technique is applied by troops in China and Russia [2]. The PLF technique has two phases namely foot strike and roll over [3] in contrast to the HSPL technique which only knees, ankle and forefeet hugging each other with plantar parallel to the ground [4]. Foot strike is the position when both feet touches the ground. PLF technique is more convenient and effective since the rolling process can reduce the impact loads of body segment.

Various injuries occur during landing parachutists were recorded and found the highest injury was in the ankle [5,6]. Anterior cruciate ligament (ACL) was common ankle part injury during drop landing activity [7]. In biomechanical explanation, ankle is prone to injury because it is the first joint to suffer impact from the ground and it receives the impact of the full body. The exhibit greater knee flexion and the angle must less than 45° will protect from ACL [8]. Therefore, [5] there is a study about the use of ankle brace, which is tool that was created to help reduce injury on ankle. Based on the result, it has shown that the using of ankle brace can prevent the injury and also reduce the cost of medical.

The spine and pelvic area are also the parts of the body which often get injured as they stem from a strong impact on the ground when performing bad landing technique where the parachutist lands in a seated position [9]. For example, the study has recorded that there is a 29 years old military parachutist who suffered medial end clavicle fracture after a bad landing [10]. According to a previous surveys made by researchers, the data collection done only focusing on the injuries during jumping parachutes [11-14]. This proves that parachuting activities may result in a lot of injuries if they do not land perfectly.

There are many researchers who have studied kinematics and kinetic data especially in jumping activities [15-22]. In biomechanical study, [20] inverse dynamic solutions are used to estimate lower extremity joint kinematics, kinetics and energetic profiles for 60 cm drop landing activity. Few studies have collected kinematics data with different gender [2,7,17,18] and show that there are differences especially involving the ankle part during drop landing activity. Women have greater risk of injury during landing compared to men because female transform the kinetic energy to the ankle motion, whereas men are more likely to transform it to friction [2]. Terrain stiffness is also one of the factors that can cause ankle injury while landing. Because of this, [15] doing research about terrain stiffness may be necessary because the result did not show that the terrain gives significant impact to ankle due to the experiment was conducted using mats of different level of thickness.

In biomechanics study, some researchers have already made research about movement of the whole body [23,24] but neither of them made it involving parachute landing activity. Furthermore, mostly researchers have only focused on lower extremity part during landing [2-4,7-8,15-22]. This paper will cover the value of acceleration, velocity and angle for the whole-body part which are wrist, elbow, waist, knee and ankle joint. The process of motion caption analysis will be done using Quintic Biomechanics Software because of its suitability for outdoor usage. Some researchers used the same software to solve the problem in sport [25] and ACL problem [26].

Our study was designed to examine the kinematics data from professional and amateur paratroopers on sagittal plane during simulated PLF technique. The differences in the data will have shown that amateur applied the wrong technique of landing which will then cause injury. By comparing the kinematics data amateur parachutists can use the kinematics data from professionals as their main reference for parachute landing. The value of velocity, acceleration and the angle from upper and lower extremity will be determined in this paper. From the understanding of biomechanics for the parachute landing application, this would improve the parachuting training and reduce the injuries.
2. Methodology

Three professional (age, 28 ±1.73 yr; height, 1.67 ± 2 m; weight, 65.3 ± 7.6 kg) and eighteen amateur paratroopers (age, 23.8 ± 2.1 yr; height, 1.69 ± 4.9 m; weight, 62.9 ± 5.9 kg) from the Malaysian Army were recruited to participate in this study. The experiment was conducted at Training Static Parachute Landing for Malaysia Army at Kem Sungai Udang, Malacca. The selection of professional subjects was based on the experience of completing successful parachute landing without any injury. Meanwhile, selection of amateur subjects from students who are following a static umbrella jump course. The paratroopers were labelled as a professional after making 50 jumps without any injuries at a height of 1000 ft. In this experiment the selected professional paratroopers have made a jump of 53 times. All subjects have signed a written consent form approved by the university that was in accordance with the HUKM guidelines.

All subjects wore camouflage military uniform for exercise and testing, and all wore the same boots and helmet specially designed for the parasol jump. All participants also carried 2kg weight bag placed on the front of body during the landing activity. The experiment begins with one subject who will cling onto an iron swing and asks for another amateur to push him until he swings like a pendulum. Then the subject would release the iron swing and land on a mattress with the thickness of one cm by applying the PLF technique. All the subject will make landing three times for better kinetics and kinematics data result.

The kinematics data were collected using three camera GO-Pro Hero 4 with 60 frame per second at 1080 pixel of highly quality resolution. The cameras positioned haves been placed on the left, back and in front of the subject as mention in figure 1. Position camera 1 is to capture the sagittal plane, meanwhile camera 2 was placed at the back of the subject to capture frontal plane especially rolling phase. Then camera 3 was placed 60° from camera 1. Figure 2 shows the position of the subject at the sagittal plane while the subject is readying to swing. This paper only aims the kinematics data from sagittal plane.

Figure 1. Position of cameras using top view.  
Figure 2. The position of a subject on sagittal plane
The collection of data begins when the subject released the iron swing and applies foot strike. The position of foot strike will be counted when both feet landed on the ground. Joint angular position, velocities, acceleration and angle were calculated from the digitized video using Quintic Biomechanics software. In deriving the segment rotation, the flexion-extension was first rotation followed by abduction and internal external rotational respectively.

Quintic Biomechanics was used to track linear velocity, acceleration and angular rotation based on the joint segment involved during parachute landing activity which are wrist, elbow, shoulder, waist, knee and ankle joint. The calibration process was set with using 1m ruler as the benchmark and the line was created based on the position of ruler with 59.4 speed of the video. Subsequent to digitizing, the raw data were smoothened using Butterworth digital filter with the cut-off frequency of 3 Hz. The difference of data from professional and amateur’s will be analysed using T-welch t-test. Since the data from both group have a different number of size.

3. Result

3.1 Kinematics data during released iron swing

| Variable                  | Professional Mean ± SD | Professional Max | Professional Min | Amateurs Mean ± SD | Amateurs Max | Amateurs Min |
|---------------------------|------------------------|------------------|------------------|--------------------|--------------|--------------|
| Linear Velocity (ms⁻¹)    |                        |                  |                  |                    |              |              |
| Wrist flexion             | 0.56 ± 0.19            | 0.79             | 0.23             | 0.79 ± 0.37        | 1.80         | 0.16         |
| Elbow flexion             | 0.48 ± 0.23            | 0.96             | 0.21             | 0.64 ± 0.34        | 1.59         | 0.21         |
| Shoulder flexion          | 0.41 ± 0.17            | 0.76             | 0.18             | 0.61 ± 0.39        | 1.91         | 0.12         |
| Hip flexion               | 0.55 ± 0.37            | 1.42             | 0.22             | 0.47 ± 0.24        | 1.22         | 0.16         |
| Knee flexion              | 0.35 ± 0.16            | 0.72             | 0.22             | 0.46 ± 0.23        | 1.00         | 0.17         |
| Ankle flexion             | 0.56 ± 0.20            | 0.86             | 0.34             | 0.55 ± 0.37        | 1.84         | 0.13         |
| Linear Acceleration       |                        |                  |                  |                    |              |              |
| Wrist flexion             | 0.57 ± 3.8             | 8.75             | -3.62            | 2.29 ± 4.90        | 21.12        | -7.26        |
| Elbow flexion             | -0.07 ± 1.84           | 1.82             | -4.48            | 1.62 ± 5.09        | 16.31        | -16.64       |
| Shoulder flexion          | -2.29 ± 2.28           | 0.69             | -6.12            | 1.18 ± 4.83        | 10.87        | -19.31       |
| Hip flexion               | -3.11 ± 9.25           | 2.68             | -26.99           | 1.41 ± 3.39        | 8.88         | -6.57        |
| Knee flexion              | -0.76 ± 6.64           | 5.82             | -16.33           | 2.57 ± 2.81        | 9.38         | -2.93        |
| Ankle flexion             | 3.27 ± 4.51            | 9.91             | -6.08            | 3.92 ± 3.90        | 15.87        | -5.57        |
| Angle (º)                 |                        |                  |                  |                    |              |              |
| Wrist flexion             | 181.08 ± 6.98          | 196.26           | 170.22           | 171.90 ± 9.73      | 203.96       | 151.19       |
| Elbow flexion             | 151.90 ± 14.78         | 180.62           | 131.56           | 148.96 ± 17.15     | 200.60       | 111.58       |
| Shoulder flexion          | 158.93 ± 11.11         | 177.60           | 147.05           | 162.65 ± 15.27     | 226.60       | 141.60       |
| Hip flexion               | 130.25 ± 7.72          | 145.57           | 121.37           | 130.59 ± 10.87     | 152.01       | 109.33       |
| Knee flexion              | 104.10 ± 8.85          | 116.21           | 91.96            | 103.79 ± 16.36     | 137.47       | 67.76        |
| Ankle flexion             | 77.15 ± 12.04          | 97.41            | 58.05            | 76.72 ± 11.62      | 97.73        | 50.97        |
The $p$-value of linear velocity at shoulder, knee and ankle joint segment showed less than 0.05 ($p < 0.05$) where it can be concluded to have significant difference between data from professionals and amateurs. Meanwhile at wrist, elbow and waist showed the $p$-value was greater than 0.05 ($p > 0.05$). Based from Table 1 the value of mean and SD from professionals are lesser compared to the amateurs. The maximum value from professionals showed less than $1\text{ m s}^{-1}$ for every joint segment, compared to the amateur parachutists which are higher than $1\text{ m s}^{-1}$. The $p$-value of linear acceleration showed less than 0.05 ($p < 0.05$) at wrist, shoulder, waist, knee and wrist joint segment and $p$-value was greater than...
0.05 \( (p > 0.05) \) at elbow and ankle joint segment between data from professionals and amateurs. In addition, the \( p \)-value of angle at knee and ankle joint segment was less than 0.05 \( (p < 0.05) \) and show to have significant difference between professionals and amateurs. Then the \( p \)-value of angle at wrist, elbow, shoulder and hip of joint segment showed greater than 0.05 \( (p > 0.05) \). Figure 3, 4 and 5 represent linear velocity, linear acceleration and angle of professional and amateur parachutist for the first event respectively. The maximum value of joint angle at hip and knee from amateur’s data are greater than professionals’ and thus showed amateurs demonstrate a more erect landing posture.

### 3.2 Kinematics data during feet touched ground

| Variable                  | Professional | Amateurs |
|---------------------------|--------------|----------|
| Wrist flexion \( \text{ms}^{-1} \) | 2.30 ± 0.56  | 5.56     |
| Elbow flexion             | 2.38 ± 0.37  | 5.13     |
| Shoulder flexion          | 1.84 ± 0.67  | 2.06     |
| Hip flexion               | 1.93 ± 0.58  | 2.10     |
| Knee flexion              | 2.31 ± 0.35  | 2.16     |
| Ankle flexion             | 2.30 ± 0.31  | 2.03     |
| Linear Velocity \( \text{ms}^{-2} \) | 7.47 ± 3.96  | 5.56     |
| Wrist flexion             | 6.74 ± 4.29  | 8.55     |
| Elbow flexion             | 6.19 ± 3.69  | 1.64     |
| Shoulder flexion          | -0.28 ± 6.02 | -1.75    |
| Hip flexion               | -2.22 ± 8.03 | -3.41    |
| Knee flexion              | -11.74 ± 8.94| -14.94   |
| Ankle flexion             | 194.21 ± 18.46| 199.44  |
| Elbow flexion             | 133.05 ± 25.31| 129.48  |
| Shoulder flexion          | 120.30 ± 18.04| 138.20  |
| Hip flexion               | 106.35 ± 10.85| 129.34  |
| Knee flexion              | 99.91 ± 8.76 | 116.41   |
| Ankle flexion             | 56.54 ± 10.78| 80.87    |

### Figure 6. Linear velocity of the second event for (a) professional (b) amateurs parachutist
Figure 7. Linear acceleration of the second event for (a) professional (b) amateurs parachutist

Figure 8. Angle of the second event for (a) professional (b) amateurs parachutist

There is a significant difference of linear velocity between professionals and amateurs where the p-value at all joint segments was less than 0.05 (p < 0.05) during the second event. The value of SD and the maximum of linear velocity showed amateur are much greater. Meanwhile p-value for the linear acceleration show less than 0.05 (p < 0.05) at the lower extremity part which are hip, knee and ankle joint segment. It clearly showed there are significant difference of acceleration between professionals and amateurs. But on the upper extremity part the p-value was greater than 0.05 (p > 0.05) which are wrist, elbow and shoulder joint segment and there was no significant difference. The direction of the acceleration vector depends on two things whether subject is speeding up or slowing down or subject is moving in negative or positive position. In this case the mean value of velocity from professionals and amateurs are positive for all joint segments and negative value of acceleration at hip, knee and ankle joint. It showed that lower extremity part in which all subject’s move slower down during feet touched ground and the direction of acceleration are opposite with the velocity. In addition, the p-value for the angle between professionals and amateurs was greater than 0.05 (p > 0.05) at wrist and elbow joint and less than 0.05 (p < 0.05) at waist, knee and ankle joint. Based on table 2 the value of joint angle in every segment from amateurs are much greater than professionals. The value of joint angle lower extremity is smaller from professional parachutists, and it showed that they have flexed their leg to reduce the impact during landing. Figure 6, 7 and 8 represent linear velocity, linear acceleration and angle of professional and amateur parachutist for the second event respectively. Based on the p-value during this event it clearly show that are different value of linear velocity, linear acceleration and angle between professionals and amateurs especially at lower extremity part. It can be concluded amateurs apply the wrong technique during feet touched ground and it will cause the injury.
4. Discussion
This study found that professional and amateur parachutists have significant difference in kinematics data in whole body while performing a PLF technique activity. There are two events that were accounted for in this paper which are the release of iron swing and before feet touch the ground. These two events were taken because want to identify whether or not amateurs apply the right PLF techniques during landing. The angle of joint segments for professionals are smaller during the second event especially at the lower extremity part compared to amateur parachutists. Figure 5 and figure 8 clearly show that angle of joint segments involved give significant difference between professional and amateurs parachutist. Maximum angle is not more than 230 and 280 for professionals and amateurs respectively. Moreover, angle at hip joint from professional are much more less compared to amateur parachutist. It can be concluded that professional parachutists had bend their hip and flexed the ankle during preparation landing to reduce the impact force during landing. Knee is one of the joints that are prone to injury during landing activity [5,6], because it is the first joint to suffer impact from the ground and it receives the full body. Table 2 showed the value mean and minimum value from professionals at ankle joint angle was only 56.54 and 45.88 meanwhile amateurs reach 80.87 and 58.37°. According to [28] flat-footed landing will result in fewer injury compared to toe-first because it has less flexion during the initial impact phase and sustained higher peak ground reaction forces. To get a landing with a flat-foot, the angle of ankle joint must be ± 45° if the angle reaches more than 60° the land will landed with toe first.

The velocity value of mean, SD, maximum and minimum of all joint segments from first event have significant increase during the second event. Table 1 and table 2 showed the positive value of linear velocity and it is because all subjects are moving forward and the distance of movement are increasing during foot touched the ground. Meanwhile figure 3 shows a significant difference of linear velocity between the professional and amateur parachutist in the first event, where the value for the amateur parachutist has reached 8 ms⁻¹ compared to the value for the professional which has only reached 3 ms⁻¹. Figure 6 illustrates that for the second event, the velocity of every joint segments of the professional parachutist is seen to have moved more evenly and retained the same value of velocity compared to the amateur’s value of velocity which is seen to exhibit a decrease. Nevertheless, the value is still higher than the professional’s especially for the wrist joint.

On the other hand, the mean value of linear acceleration during the first event where professional parachutist’s haves negative value of acceleration on elbow, shoulder, hip and knee joint shows that the movement slow down with the different direction of velocity. Vice versa with the acceleration result for amateurs where all the mean value is positive in every joint segment during first event. It showed the movement is speeding up with same direction of velocity. Figure 4 and figure 7 highlight of linear acceleration of every joint segments between professional and amateur parachutist at first and second event.

As what have been hypothesized, knee and ankle joint were the lower limbs that will have suffered injury when landing technique is applied. ACL is the most common injury ankle part during drop landing activity [7]. Based on previous study [29] researchers measured the tension of ACL while knee conducting flexion and extension. They also found that the knee flexion torque was significant correlated with ACL problem. Some researchers [5] also found the solution to reduce ACL problem is by using the ankle brace for army parachutist during parachute landing activity.

The equipment for personal protection and the combat purposes places additional weight on the parachutist body, which also might give effects to kinematics and kinetics data and also the risk of musculoskeletal injuries. Previous study [27] has demonstrated that effect of additional weight on knee kinematics and vertical ground reaction force (VGRF) of soldier performing a two-legged drop landing activity. The result showed even with the minimum additional weight soldiers carry such as the addition of body armour, helmet, boots, and rifle can give effect in the kinematics and ground reaction forces.
This study analysed the difference of kinematics data from professional and amateur parachutists based on two events where during subject released the iron swing and feet touch the ground on the sagittal plane. As discussed, the professional’s data can be used as the main reference for amateurs to perform parachute landing and reduce injury. Future research shall investigate other event in PLF technique which is rolling phase. Since spine and pelvic are also body parts which often injured during parachute landing activity.

5. Conclusion
The result of this study provided a lot of information for a better understanding in biomechanics study for parachute landing activity between professional and amateur parachutist. The hip and knee flexion movement during landing will reduce the impact in landing phase. Ankle injury also can be reduced by applying flat footed technique during feet touch the ground. The value of velocity, acceleration and angle in every joint segment from professionals can be used as a main reference for amateurs to perform parachuting training and reduce the injuries.

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7. Reference
[1] Chervak M C, Hooper T I, Brennan F H, Craigh S C, Girasek D C, Schaefer R A, Barbour G, Ywe K S and Jones B H 2010 Am J Prev Med. 38(1) pp 11–18
[2] Niu W, Wang Y, He Y, Fan Y and Zhao Q 2010. Aviation, Space, and Environmental Medicine 81(8) pp 761-767
[3] Whitting J W, Steele J R, Mark A, Jaffrey M A and Munro B J 2007 Aviation, Space, and Environmental Medicine 78(12) pp1135-114
[4] Chappell J D and Limpisvasti O 2008 American Orthopaedic Society for Sports Medicine 36(6) pp 1081-1086
[5] Knapik J J, Spiess A, Swedler D I, Grier T L, Darakjy S S and Jones B H 2010 Am J Prev Med. 38(1) pp182-188
[6] Neves E B, Souza M N and Almeida R M V R 2009 Military parachuting injuries in brazil Injury 40(1) pp 897-900
[7] Kernozek T W, Torry M R, Hoof H V, Cowley H and Tanner S 2005 Journal of the American College of Sports Medicine 37(6) pp1003-1012
[8] McNitt-Gray J L 1991. Int J Sport Biomech 7 pp 201-24
[9] Hasler R M, Hu H E, Keel M J B, Durrer B, Zimmermann H, Aristomenis K, Exadaktylos A K and Benneker L M 2012 Injury 43 pp 440-445
[10] Bourghlia A and Fabreb A 2011 Orthopaedics & Traumatology: Surgery & Research 98 pp 238-241
[11] Ball V L, Sutton J A, Aicha Hull A and Sinnott B A 2014. Wilderness & Environmental Medicine 25 pp 89-93
[12] Ellitsgaard N 1987 Injury 21(1) pp13-17
[13] Bricknell M C M and Craig S C 1998 Occup. Med. 49(1) pp17-26.
[14] Ekeland A 1997 International Journal of the Care of the Injured 28(3) pp 219-222
[15] Niu W and Fan Y 2013 Aviation, Space, and Environmental Medicine 84(12) pp 1262-1267
[16] Kwok P, Kong W, Kasturi K, Lee C and Hamilll J 2003 17th AIAA Aerodynamic Decelerator System Technology Conference and Seminar pp 19-22
[17] Huston L J, Vibert B, Ashton-Miller J A and Wojtys E M 2001 *The American Journal of Knee Surgery*. 14(4) pp 215-220
[18] Decker M J, Torry M R, Wyland D J, Sterett W I and Steadman J R 2003 *Clinical Biomechanics*. 18 pp 662-669
[19] Colby S, Francisco A, Yu B, Kirkendall D, Finch M, J and Garret W 2000. *Am. J. Sport Med*. 28 pp 234-240.
[20] Protopapadaki A, Drechsler W I, Cramp M C, Coutts F J and Scott O M 2007 *Clinical Biomechanics*. 22 pp 203–210
[21] Chappell J D and Limpisvasti O 2008. *American Orthopaedic Society for Sports Medicine*. 36(6) pp1081-1086
[22] Chappell J D, Herman D C, Knight B S, Kirkendall D T, Garrett W E and Yu B 2005 *American Orthopaedic Society for Sports Medicine*. 33(7) pp 1022-1029
[23] McLean S G, Huang X, Su A and Van de Bogart A J 2004 *Clinical Biomechanics*. 19 pp 828-838
[24] Damsgaard M, Rasmussen J, Christensen S T, Surma E and Zee M D 2006 *Simulation Modelling Practice and Theory*. 14 pp 1100-1111
[25] Munro A, Herrington and Comfort P 2012 *Physical Therapy in Sport*. 13 pp 259-264
[26] Munro A and Herrington L 2014 *The Knee*. 21(5) pp 891-895
[27] Sell T C, Chu Y, Abt J P, Nagai T, Deluzio J, McGrail M A, Rowe R S and Lephart S M 2010. *Military Medicine*. 175(1) pp 41-47
[28] Whitting J W, Steele J R, Jaffrey M A and Munro B J 2009 *Military Medicine*. 174 pp 832-837
[29] Fleming B C, Ohlen G, Renstrom P A, Peura G D, Beynnon B D and Badger G J 2003 *Am. J. Sports Med*. 31:701-707