# Ground Reaction Forces and Electromyography in a Parkour Obstacle Course

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Science

in

Sport and Exercise Science

At Massey University, Wellington, New Zealand

Marcel Austmann

2019

## Abstract

Parkour is a physical discipline that involves athletes, also known as traceurs, using specific skills and movements to overcome obstacles in an urban environment. A typical parkour landing involves an ever-changing combination of variables such as speed, agility, and multiple movement skills that in turn may affect the forces placed on the body. The purpose of the present study was to design a field-based protocol that measured and compared the forces athletes are exposed to in their natural training environment. **Methods:** A parkour specific obstacle course was designed and five experienced traceurs completed the series of obstacles in succession. Between obstacle comparisons were made for ground reaction force (GRF), time to maximal ground reaction force (TTP), and rate of force development (RFD). Additionally, electromyography was assessed to help better describe underlying mechanisms associated with differences in landing forces. Electrodes were placed bilaterally on the vastus lateralis (VL), gastrocnemius (GM), and the tibialis anterior (TA) and area (%MVIC) was used to represent muscle activation. **Results:** GRF was highest in obstacles with larger drop heights as well as increased momentum from previous obstacles which includes obstacles 2a-floor, 4-floor, and 2c-floor. The lowest TTP values were associated with obstacles involving short landing contact time due to limited space which includes obstacles 3-4, 2c-floor, and 1-floor. RFD was greatest in obstacles 2a-floor, 3-4, 4-floor, 9-floor, and 2c-floor which all required explosive power upon landing in order to complete subsequent obstacles. EMG data showed that the GM and VL had greater activation on obstacles requiring either a change in direction such as 6b-7 and/or a rapid descent such as obstacles 7-8 and 8-floor. TA showed higher activations on obstacle 9-floor and 2b-2c, but activations were similar across most obstacles. The activation of the TA may be due to its role in eccentrically contracting during initial foot strike during landing. **Conclusion:** Due to the dynamic nature of parkour, athletes are often exposed to a variety of landings which would produce diverse kinetic demands. By using a parkour specific course, this study provided force data that was a close representation of the forces traceurs are exposed to in a typical parkour run.

# Acknowledgements

I would first like to thank my thesis supervisor Dr. Sarah Shultz for her guidance, support, and encouragement throughout the entirety of this project. Dr. Shultz always made herself available when I required assistance and never failed to provide answers or solutions to any questions or problems I encountered. I would also like to thank Stacey Kung and Mostafa Yaghoubi for providing their expertise in several aspects of this study including familiarization with equipment, testing protocols, data analysis, and providing constant support. Without this amazing research team, I would not have been able to achieve what I have with this project. I would also like to acknowledge and thank Dion Doutré and all the staff at the Flow Academy in Albany. By allowing us to use your facility you made this project possible and for that I am eternally grateful. This project was approved by the Massey University Human Ethics (Southern A) Committee.

# Contents

# List of tables

# List of figures

# Chapter 1

## Introduction

Parkour is a physical discipline that involves athletes, also known as traceurs, using specific skills and movements to overcome obstacles in an urban environment (18). Parkour athletes utilise a variety of movements including jumping over ledges, climbing walls, vaulting, and traversing between obstacles (3). Essentially, the goal of parkour training is to improve one's skills in overcoming obstacles in a safe and efficient manner (18). Parkour is said to have originated in France in the 1980's with its emergence being strongly influenced by David Belle and Sébastien Foucan (3). Moreover, parkour was often used as a training method in the French military for its functional and utilitarian purpose in obstacle manoeuvres (7). Over the past few decades parkour has gained considerable popularity due to increased exposure through social media (43). As a result, there has been an influx in youth and adults attempting this activity globally.

Currently, parkour is still regarded as a relatively new sport and therefore research in this field is limited. More specifically, there appears to be a gap in knowledge concerning the forces associated with parkour landings and subsequent links to injury or performance. Ground reaction force (GRF) plays a significant role in a majority of sports as it quantifies the magnitude of stress placed upon the body as it contacts the ground (39). In sports such as gymnastics, football, and volleyball GRF magnitudes have been recorded upwards of several times the player's bodyweight (42, 49, 57, 62). The accumulation of impact forces can result in additional stress on the musculoskeletal system, which must be dissipated to reduce the chance of structural damage (55). When the body is unable to disperse these forces effectively, several injuries may occur including shin splints, patellofemoral pain syndrome, anterior cruciate ligament tears, tendinitis, fractures, and dislocations (17, 44, 54, 56). Parkour is already considered an extreme sport associated with high risks (6) because of the diverse landings from heights on to hard surfaces such as concrete, wood, metal rails, and other rough and unpredictable terrain (59). However, it is difficult to fully recognize the risks posed to traceurs without an understanding of the specific loads that are being demanded on the lower extremity.

Appropriate landing techniques are fundamental to many sports; thus, there is an abundance of research placed on the kinematic and kinetic variables associated with landing biomechanics. Previous research has shown that increased flexion at the hips, knees, and ankles during landing increases the contribution of the lower limb musculature and significantly reduces GRF (20, 61, 71). Studies investigating landing acoustics have demonstrated that softer landing sounds were associated with greater lower limb muscle activation as well as reduced GRF (66). Time to peak GRF has also been considered an influential factor in GRF as it has been proposed that an increased amount of time allows for excess force to be absorbed by the muscles (14, 15). To date few studies have investigated the forces associated with landing in parkour (36, 53, 63). These limited findings have indicated that landing technique plays a crucial role in reducing GRF. For example, utilization of the parkour precision landing technique significantly reduced vertical GRF, loading rates, and even landing sound while subsequently increasing time to peak GRF (36, 53, 63). Similar to what previous research has shown, the precision landing, which involves simultaneous flexion at the knee, hip, and ankle, appears to increase the contribution of the muscular system and reduce landing force.

The common strategy used for comparing kinematic and kinetic variables during landing in parkour and non-parkour activities incorporated a box drop landing protocol. While the box drop landing is easily standardised for laboratory testing, it does not mimic the dynamic nature of parkour training and performance. Specifically, a typical parkour landing involves an ever-changing combination of variables such as speed, agility, and multiple movement skills that in turn may affect the forces placed on the body. The purpose of this study was to design a field-based protocol that measured and compared the ground reaction forces associated with a variety of parkour landings. A parkour specific obstacle course was used where traceurs completed a series of obstacles using their own desired movements. The current study aims to provide kinetic data that is a close representation of the forces athletes are exposed to in their natural training environment. In addition, electromyography (EMG) was assessed to help better describe underlying mechanisms associated with difference in landing forces.

## Literature review

**Abstract**

The purpose of this review was to identify relevant literature on the factors affecting ground reaction forces (GRF) in parkour. Due to the requirement of landing movements in sport there is an abundance of research addressing the biomechanics involved. Furthermore, most studies have investigated this topic using key variables such as landing technique, impact velocity, loading rates, landing sound, and muscular activation through electromyogram (EMG). In addition, the drop landing task appears to be the most common method used for measuring these variables. Unfortunately, due to the relative infancy of parkour, little research was identified. However, current literature suggests landing technique plays a significant role in force attenuation in parkour. It has been shown that a forefoot landing with simultaneous flexion at the hip and knee results in significant decreases in GRF and loading rates. However, more research is required that addresses factors affecting GRF in parkour as well conditioning and injury prevention strategies.

**Introduction**

Jumping and landing are regarded as fundamental movements in most sporting activities(27, 39, 49, 62). However, during these movements the body is suggested to experience significant impact loading particularly during landing (70). The accumulation of high impact forces may have harmful effects on the lower extremities which may lead to injury (55). GRF is an important factor in many impact sports as it is a measure of the magnitude of stress placed upon the body as it makes contact with the ground (39). The forces associated with landing in popular sports such as netball, gymnastics, volleyball, and football, have been reported at values up to several times body weight (42, 49, 62). Due to the requirement of landing in sport, there has been an abundance of research placed on landing biomechanics in more common sports. However, parkour, which is a relatively new and unknown sport has not received as much attention. Parkour is described as an extreme sport where athletes will perform a variety of acrobatic type movements in an urban environment (7). This may include jumping over ledges, climbing walls, and traversing between obstacles (3). Due to the extreme nature of parkour where landing movements are crucial to both safety and performance there is a need for more research. The purpose of this review is to identify what is currently known regarding GRF and landing in parkour. Due to the abundance of research on landing in more common sports, these will also be reviewed as these may also be applicable to parkour.

## FACTORS AFFECTING GROUND REACTION FORCE IN SPORT

Ground reaction force is an important factor in many impact sports as it is a measure of the magnitude of stress placed upon the body as it makes contact with the ground (39). In popular sports, GRF has been shown to increase significantly. For example, peak vertical GRF during single leg landing from a somersault in gymnasts have been reported at values as high as 14.4 times bodyweight (49). Stacoff et al. (62) reported that GRF associated with landing after a volleyball block jump had peak values of up to 6000 Newtons (N). In military paratroopers, GRF have been recorded at values as high as 17 times body weight upon landing (25). The forces associated with these landing activities have been linked to several injuries including shin splints, patellofemoral pain syndrome, anterior cruciate ligament tears, tendinitis, fractures, and dislocations (17, 44, 54, 56). Due to landing movements being a necessity for most sports there is an abundance of research placed on landing biomechanics. Furthermore, out of these studies, several common variables have been identified that have been used to investigate what may influence these forces. Specifically, this includes kinematic variables such as landing technique (21, 61, 71), muscular activity (EMG) (29, 33), landing velocity (25, 42), landing sound (63, 66), and time to peak force/ loading rates (14, 15, 63, 67). Additionally, the most common method used in assessing these variables is through drop landing tasks usually at various heights.

### Lower limb kinematics and ground reaction force

One variable that has been measured in numerous studies is landing technique. For instance, research investigating landing strategies has shown that the stiffness of the landing may influence force dissipation. This was seen in a study by Zhang et al. (71), who investigated energy dissipation during drop landings. Their study demonstrated that landing stiffness was associated with a decrease in the ability to dissipate mechanical energy. Additionally, this study found that the soft landings involved a greater contribution of the knee and hip extensor musculature whereas the stiff landing mainly involved the ankle planter flexors. Devita and Skelly (21), who examined the effect of landing stiffness on joint kinetics and energetics also reported higher GRF during stiff landings. Similar to the first study, higher activation of the ankle planter flexors was observed during stiff landings, however, greater activation of the hip and knee extensors were observed in the soft landing. Slater et al. (61), who assessed landing stiffness on peak vertical GRF in artistic gymnasts again had similar findings. By allowing greater flexion at the hip, knee, and ankles upon impact, gymnasts significantly reduced peak vertical GRF as well as increased time to peak. Time to peak GRF has also been considered an influential factor in GRF as it has been suggested that this increased time allows for excess force to be absorbed by the muscles (14, 15).

Foot position during landing is also considered a key factor in force dissipation and has been shown to influence subsequent movement at the hips and knees. This was observed in a study by Whitting et al. (67) who examined whether landing foot pitch affected vertical GRF in military parachutists. What they discovered was that those who used a flat foot landing had reduced knee and ankle flexion, higher peak vertical GRF, as well as faster times to peak. In comparison, those who landed on the ball of the foot had lower GRF, a slower time to peak as well as increased knee and ankle flexion. Again, this study highlights that the time to peak or the rate of force development plays a significant role in force dissipation. Foot landing strategy was also investigated by Cortes et al. (15), who assessed lower limb kinematics during various foot landing strategies (forefoot, habitual, and rear foot) in recreationally trained athletes. The study showed that peak vertical GRF was highest in the rear-foot landing technique. Furthermore, it was observed that this technique involved the lowest knee flexion angles. Together, these studies suggest that certain kinematic variables such as hip, knee, and ankle movement upon landing play a crucial role in reducing GRF. It is important to note that the studies mentioned here only cover a small sample of the studies identified that have addressed landing kinematics (6, 45, 47, 51, 60, 68, 69). However, these studies provide evidence that GRF is influenced by landing technique.

**Upper limb kinematics and ground reaction force**

Most studies have shown that lower limb kinematics play the largest role in GRF. However, upper body kinematics may also influence GRF. Blackburn and Padua (8) demonstrated that active trunk flexion during drop landings in healthy men and women produced concomitant increases in both hip and knee flexion which in turn reduced GRF. In comparison, it has been shown that a more upright torso as well as abdominal bracing during landing may have the opposite effect. In a recent study by Campbell et al. (11) abdominal bracing during a drop landing task in healthy adults was accompanied by reduced hip and knee flexion as well as increased vertical GRF. Using the braced abdominal strategy upon landing appears to have had a similar effect to the stiff landing of the lower body which resulted in a decreased ability of the body to attenuate force. The upper limbs have also been shown to affect lower limb kinematics during landings tasks. For example, Masters et al. (38) assessed whether or not arm position during single leg box drops would affect lower limb kinematics in American football players. The arm positions included a control where the arms were free, arms to the landing limb side, arms in front of the body, and arms away from the landing limb. The study found that landing with arms away from the landing limb significantly decreased hip flexion and increased dorsiflexion. However, it was also suggested this may be the result of reduced stability which challenged normal landing movements.

**Landing velocity and ground reaction force**

There is evidence suggesting that the velocity of impact during landing may also influence GRF by modification of landing technique. This was observed by McNitt (41) who assessed landing strategy preference and lower limb kinetics in gymnasts and recreational athletes during drop landings. The study found that increases in impact velocities were accompanied by larger hip and ankle moments which resulted in reduced GRF. Interestingly, larger extensor moments were found in the gymnasts compared to the recreational athletes. This was suggested to be due to gymnasts having to often stick their landings (i.e. no additional steps) which requires a higher level of control and balance (41). As it was seen in the study by Masters, reduced balance may impair landing ability. In military paratroopers, velocities measured during the descent phase prior to landing have been recorded at values up to 6.7 $ms^{-1}$ (25). Moreover, it has been shown that the GRF associated with landing within these velocity ranges can result in GRF of up to 17 times bodyweight (25). Although this would not be considered a common sport or activity, it is stated that GRF can significantly increase at high velocities as well as with lower limb stiffness (10, 71). Again, this further suggests landing technique as well as the muscular system will also play a role in mitigating forces particularly at higher velocities.

**The role of the muscular system in force dissipation**

The studies mentioned provide evidence that landing technique plays a major role in force dissipation which in turn is likely due to the contribution of the muscular system. This has been explored in several studies by measuring electrical activity of muscle upon landing via EMG. One study in particular was by Kellis and Kouvelioti (29), who measured EMG activity of the knee flexors and extensors during a drop landing task. The authors reported that greater knee flexion was associated with an increased activation of the quadriceps as well as reduced vertical GRF. Similar results were observed by Leporace et al. (33) who found that the rectus femoris, a knee extensor, had significantly higher activation 100ms post landing compared to 100ms prior to landing in male volleyball players. Interestingly, activation patterns of lower limb muscle groups during landing have also been shown to impact joint functional stability. This was observed in a study by Suda et al. (64) who compared activation patterns in the ankle muscles of volleyball players with and without ankle instability. The study found that players with no instability had a simultaneous contraction of the peroneus longus and gastrocnemius lateralis with the tibialis anterior activated after impact. In comparison, in player who had ankle instability, all three muscles activated simultaneously. This may be the result of neuromuscular control which may in turn predispose athletes to ankle sprains (37).

These studies emphasise the important role of the lower limb musculature in force dissipation and joint integrity during landing tasks. According to the literature, the muscular system plays a significant role in attenuating the mechanical stress placed on the body during landing (29). Essentially, the muscular system is said to act as a shock absorber due to their ability to dissipate kinetic energy during landing and other deceleration movements (31). The ability of the muscle to dissipate energy is through active lengthening of the muscle fascicles which in turn converts mechanical energy into metabolic heat (1). During force dissipation, the tendons may also act as a buffer by temporally storing elastic energy which not only provides energy for subsequent movements but also reduces peak forces placed on the muscles (58). In addition, it is stated that the magnitude of force to muscle is at its greatest when the external force exceeds the internal force by the muscles which results in eccentric contraction (35). The eccentric phase has been said to produce forces up to 140% greater than those of concentric and isometric contractions (48). However, this can result in significant mechanical stress which may increase the chance of muscular damage or injury (52). As mentioned, the forces placed on the body during landing can be several times bodyweight. Therefore, the ability of the muscles to withstand and absorb excess forces is paramount to both performance and safety (32).

**Landing sound and ground reaction force**

Although little evidence was found, it has been shown that a relationship may exist between landing sound, GRF, as well as lower limb kinematics. Wernli et al. (66), who investigated this relationship during a box drop task in physically active men found that decreased sound upon landing was accompanied by a decrease in GRF. Additionally, it was observed that these landings produced higher levels of muscular activity particularly at the knee and ankle. These findings agree with previously mentioned studies as increased flexion of the lower limbs has been shown to increase muscle activation which in turn allows more efficient energy absorption through the muscles. However, landing sound is a variable that needs further research.

**Parkour**

Parkour is derived from the French word parcourt meaning “obstacle course” and was created by David Bell and Sebastien Foucan in the suburbs of Paris in the 1980’s (43)**.** Parkour is inspired by human movement and is often described as a type of acrobatic street activity that involves an athlete manoeuvring themselves over objects and spaces in an urban environment (7). This may involve a variety of movements including jumping over ledges, climbing walls, balancing, and traversing between obstacles (3). Parkour has gained considerable popularity over the last decade or so due to increased exposure through media outlets (43). As a result, there has been an influx in youths and adults attempting this sport (43). This may be problematic however as due to the nature of parkour it is often considered an extreme sport with high risks (24, 43). For example, in addition to the variety of movements, parkour is often performed on hard surfaces such as concrete and other rough terrain (59). Unfortunately, parkour is still a relatively new and unknown sport and therefore research is limited. More specifically, there appears to be a gap in knowledge on the ground reaction forces associated with parkour landing as well as any potential links to injury. As discussed, increases in ground reaction force result in additional stress on the musculoskeletal system which must be dissipated to reduce structural damage. This holds great significance here as due to the extreme nature of parkour, landing movements are crucial to both safety and performance. Furthermore, due to the height of drop landings (sometimes over 2 meters) as well as the rough surfaces used, these forces may potentially be even greater. Therefore, to provide a greater understanding of landing in parkour and potentially reduce the chance if injury, additional research is required.

**History and distinction between parkour and free running**

According to the literature the terms parkour and free running are often used synonymously. However, it is important to note the distinction between these terms. Parkour is often described as original parkour which was first utilised in the French military where it was used as a training method for its functional purpose (2). Essentially, the goal of parkour is to simply improve one’s skills in overcoming obstacles in the safest and most efficient manner (18). For example, a traceur may use certain jumps and vaulting movements to move through obstacles safely which may be used to escape from harm or even to help those in danger. In comparison, free running often uses similar movements in parkour, however, involves more aesthetic and expressive skills such as flips and other acrobatic movements (3, 5). In some parts of the world free running has even been further developed and commercialised into competitive sporting events such as Red Bulls art of motion and Barclaycard Free-Running World Championship (5, 46).

**Factors affecting ground reaction force in parkour**

Numerous studies on more common sports and activities have provided strong evidence that landing technique has a significant influence on the forces acting on the body. Unfortunately, although some studies have looked into muscular fitness and performance of parkour athletes (24, 37), very few were identified that investigated landing and their associated forces. One study by Puddle & Maulder (53), aimed to address this topic by comparing GRF as well as loading rates associated with two landing variations in healthy parkour athletes. The variations included a forefoot only (parkour precision landing) as well as a forefoot to heel (traditional landing) which were performed from a drop landing from a 0.75m platform. This study found that the parkour precision landing had significantly less vertical GRF (38%) and loadings rates (54%) compared to the traditional landing. It was therefore concluded that the parkour precision landing was a safe landing strategy. Interestingly, this study also mentions that the precision landing involves increased hip, knee, and ankle flexion to allow for improved force reduction. According to the previously mentioned studies, the increase in flexion at the ankle, knee, and hip (soft landing) allows the major muscle groups of the lower limb to absorb additional forces.

In a second study by Standing and Maulder (63), GRF as well as landing sound was measured at two drop heights in recreationally trained and parkour athletes. Both groups were instructed to use their own traditional landing strategies to assess natural movement. It was revealed that the parkour group had significantly lower GRF (39.9%) than the recreational athletes as well as a longer time to peak force (68.6%.), and lower loading rates (65.1%). Maximal sound was also lower in the parkour group (3.6%) however this was not regarded as significant. This low significance is an interesting finding however as the previous study mentioned by Wernli et al. (66) found a strong relationship between low landing sound and reduced GRF in physically active males. It was concluded that the traditional parkour landing (precision landing) placed less stress on the body which resulted in a more effective landing strategy. Similar to the first study by Puddle and Maulder, it would appear that the precision landing strategy used in parkour provides an effective strategy for reducing GRF and stress to the body. An additional finding was that the parkour group utilised the forefoot or precision landing in 93.2% of the trials whereas the recreational group only used this strategy in 8.3% of the landings. Again, as seen in the previous studies on parachutists, gymnasts, and recreational athletes, the position of the foot during landing plays a significant role in lower limb kinematics and force dissipation.

Finally, in a recent study by Maldonado et al. (36) the precision landing was analysed in both traceurs and untrained individuals. The study involved a drop landing protocol at two heights (30cm and 60cm) and used motion capture to evaluate lower limb kinematics of the hip, knee, and ankle. Parkour athletes were instructed to land using the precision landing technique. The untrained group, however, were instructed to land with feet together in a stable position on the force platform as they were not familiar with the precision technique. The researchers found the landing duration of the parkour group was twice that of the untrained group. Furthermore, the parkour group had greater knee flexion, lower peak knee torque as well as the knee accounting for half of the energy dissipated. Interestingly, it was also observed that the landing height did not alter joint mechanical energy dissipation between the ankle, knee, and hip. As with the previous studies, the precision landing appears to be an effective landing strategy in parkour.

**Parkour studies using non-standardised drop landing methods**

The parkour articles mentioned provide insight into how landing technique such as the precision landing can greatly influence GRF. However, as a sport, parkour is often performed in an urban environment on a variety of obstacles as well as involving variables such as speed, duration, and multiple skills. Therefore, it is difficult to say whether standardised landing protocols accurately represent key variables such as the GRF in parkour. Unfortunately, only one study was found that included these variables using a parkour obstacle course. Dvořák et al. (22) investigated the reliability of a parkour skills assessment tool which was conducted in a parkour specific obstacle course. This study used a qualitative approach which used video to analyse the movements used throughout the obstacle course. Although this study did not measure GRF or other kinematic variables it was concluded that their evaluation tool was highly reliable for field parkour skill assessment.

**Injury in parkour**

Unfortunately, as well as research on parkour landing biomechanics being scarce, there have been several case studies reporting parkour related injuries. Moreover, these case studies show that landing movements are the most common cause of injury which are often the result of landing from jumps, drops, or flips (19, 23, 40, 43, 65). These are summarised in table 1. Currently, knowledge on the risk factors associated with parkour are limited (59). Therefore, research addressing potential risk factors as well as guidelines for injury prevention and training is warranted.

Table 1. This table provides a summary of parkour related injury case studies

| Age/gender | Cause of injury | Location of injury | Diagnosis | Source |
|---|---|---|---|---|
| 18 years (male) | landing | foot | Fracture/dislocation | Miller & Demoiny (43) |
| 31 years (male) | Lift-off during jump | foot | Planta fascia rupture | Blanco & Lee (9) |
| 19 years (male) | Landing | calcaneus | Fracture | Frumkin (23) |
| 13 years (male) | Landing | kidney | laceration | Vivanco-Allende et al. (65) |
| 16 years (male) | Landing | Distal radialis | fracture | Mclean et al. (40) |
| 13 years (male) | Landing | Distal tibia | Fracture | Mclean et al. (40) |
| 24 years (male) | Flipping | Spine | Fracture | Derakhshan et al. (19) |

**Limitations and future research**

To address this topic further and increase the current knowledge base of parkour research several areas require further investigation. For instance, although current research on parkour has demonstrated that the parkour precision landing is a safe and effective strategy it is unknown whether this is applicable to other sports where landing movements are a necessity. Another possible limitation and opportunity for further research is that the standardization of the drop landing procedure may not be an accurate representation of the forces associated with natural parkour movements. For example, parkour is often performed in an urban environment on a variety of obstacles as well as involving variables such as speed, agility, and duration (43). This also extends to other studies that have mostly used drop landings at set heights with set instructions as this again may not reflect unanticipated movement as well as subsequent movements or movements prior to landing. A final opportunity for further research is addressing injury prevention and exercise prescription for those that are new to parkour. As the studies by Puddle and Maulder show, experienced parkour athletes can mitigate forces through landing technique. However, no research has addressed strength and conditioning and injury prevention for beginners. Due to the extreme nature of parkour and the associated risks, appropriate strength and conditioning for beginner parkour athletes may improve safety and performance. Parkour practitioners are often encouraged to utilize proper technique, use adequate stretching, use appropriate conditioning as well as gradually progress from simple to difficult tasks to reduce the chance of injury (30). However, specific guidelines for technique, types of conditioning, and how to progress would be highly beneficial for both parkour practitioners and coaches.

**Conclusion**

In summary, landing movements are fundamental to parkour as well as many other sports. The ground reaction forces associated with landing can increase significantly upon impact. In turn these forces can be detrimental to the body and have been linked to several injuries. An abundance of research has been placed on landing biomechanics in sport. Going by current literature, most studies on this topic have focused on key variables such as, EMG, landing technique, landing velocity, and landing sound with many utilizing the drop landing method. Overall, the identified studies show that landing technique can greatly influence GRF as increasing flexion of the hip, knee and ankle allows the muscular system to efficiently dissipate excess force. Although only limited studies were found for parkour, similar results were found in these studies suggesting landing technique reduces GRF in parkour and non-parkour sports. However, to better understand landing biomechanics as well as performance in parkour, more research is required.

# Chapter 2

## Materials and methods

**Participants**

Five males (age 30.2±2.7 years, height: 175.7±8.14cm, mass: 75.85±14.71kg) with parkour experience (5.2±3.44 years) volunteered to take part in this study. Participants were required to have a minimum of 6 months parkour training experience, thus ensuring that all participants had the necessary conditioning to safely perform the course. Additional exclusion criteria addressed safety and performance: any lower extremity injuries within the past 6 months, balance and coordination conditions, or any other health concerns that may prohibit completion of the course. Participants were instructed to wear their preferred training clothing and shoes; however, they were asked to wear shorts for accessibility when attaching EMG electrodes. All participants provided informed written consent prior to participation and the study was approved by the Massey University Human Ethics (Southern A) Committee.

**Course description**

The course, which was located in a parkour training facility, included a total of 9 parkour obstacles; these obstacles were constructed using plywood for the exterior and supported by timber framing (see Figure 1). The two largest obstacles (obstacle 2 and 6) had multiple sections which were broken into parts (2a/2b/2c and 6a/6b, respectively) and participants were instructed to use the same sections of these obstacles. Additionally, obstacles 1 and 2 were used twice (bidirectionally) in this course. The method for clearing obstacle 1 was the same bidirectionally; however, participants overcame obstacle 2a in the forward direction and then 2b and 2c upon return. A bench located at the beginning of the course was used as the start and finish points for the course. Timing gates (Brower system; Draper, UT, USA) were positioned directly in front of the start/finish bench and were used to measure the time it took participants to complete the course. A webcam was placed above the starting bench and a second camera (GoPro Hero 5 set to 60fps at 1080 resolution) was placed at the opposite end of the course behind obstacle 7. Both cameras were used to identify the type of landings performed after each obstacle. The participants were provided a tour and instructions prior to completing familiarisation trials so that they understood the layout of the course and the task. Participants then performed familiarisation trials of the obstacle course to ensure that the participant was comfortable and competent with completing the course. Familiarisation trials were limited to a total of five practice runs to minimise the effects of fatigue; all participants reported being comfortable with the course and did not request more than the five trials that were allowed.

**Procedure**

Prior to testing, participants were fitted with electrodes for muscular activity and insoles to measure vertical GRF. An 8-channel wireless EMG system (Model 542 DTS EMG, Noraxon USA Inc., Scottsdale, AZ) was used to measure bilateral muscle activation of the vastus lateralis (VL), gastrocnemius medialis (GM) and tibialis anterior (TA). SENIAM guidelines were used for skin preparation and electrode placement (26). Skin preparation involved shaving and cleaning the skin using alcohol wipes. Surface electrodes (11 mm diameter; BlueSensor N, Ambu, Denmark) were placed on the belly of the muscle parallel to the muscle fibres orientation. EMG data was recorded at a frequency of 1500 Hz (input impedance: > 100 MΩ; CMRR: > 100 dB; baseline noise: < 1µV RMS; gain: 500). The EMG signal was normalised by completing maximal isometric voluntary contractions (MVIC) on the selected muscles. The MVIC protocol involved placing the lower limbs in the most effective positions for generating muscular force as recommended by the SENIAM guidelines. A break test was used where the limb was placed in position by the tester and the participant tried to break that position by maximally contracting. For the GM and TA MVIC, the subject was asked to sit in an upright position with the heel placed over the edge of a massage table. The participant was instructed to maximally plantarflex for the GM and dorsiflex for the TA against manual resistance applied by the tester. VL MVIC involved the participant sitting with the knee in line with the edge of the table and performing maximal extension at the knee against manual resistance.

Vertical GRF was measured by placing a pair of single sensor wireless insoles (loadsol, Novel Electronics, St. Paul, MN) inside participants' regular training shoes. Insoles were calibrated using a validated protocol (50) . Participants' weight was measured and converted to newtons (N) before importing the data into the loadsol iPad application. Participants were then asked to perform a 5-minute warm up of self-directed dynamic movements, which allowed the insoles to reach body temperature. After the warmup, the insoles were calibrated during a series of loaded and unloaded single leg stance conditions; participants were instructed to complete three repetitions of loading and unloading bilaterally. Insole resolution was set to 5/10 N for a range of 0-2550N.

Participants were instructed to sit in a relaxed position on the bench before the trial began and at the end of each trial to minimize any unwanted signal. When instructed to begin, the participant stood up, moved through the timing gates and proceeded to complete the course at their own pace. As parkour is about freedom of movement, participants were told to use their desired method for overcoming each obstacle. However, as efficiency is key during parkour, participants were also instructed to choose movements that allowed them to manoeuvre each obstacle as fluidly and safely as possible. In particular, highly acrobatic maneuverers such as flips were prohibited. Upon completion of the course the subject immediately sat down and relaxed. Participants were then given a rest period of up to 5 minutes. A total of 5 trials were completed. EMG, insole, video, and timing gate data were checked for quality assurance between each trial.

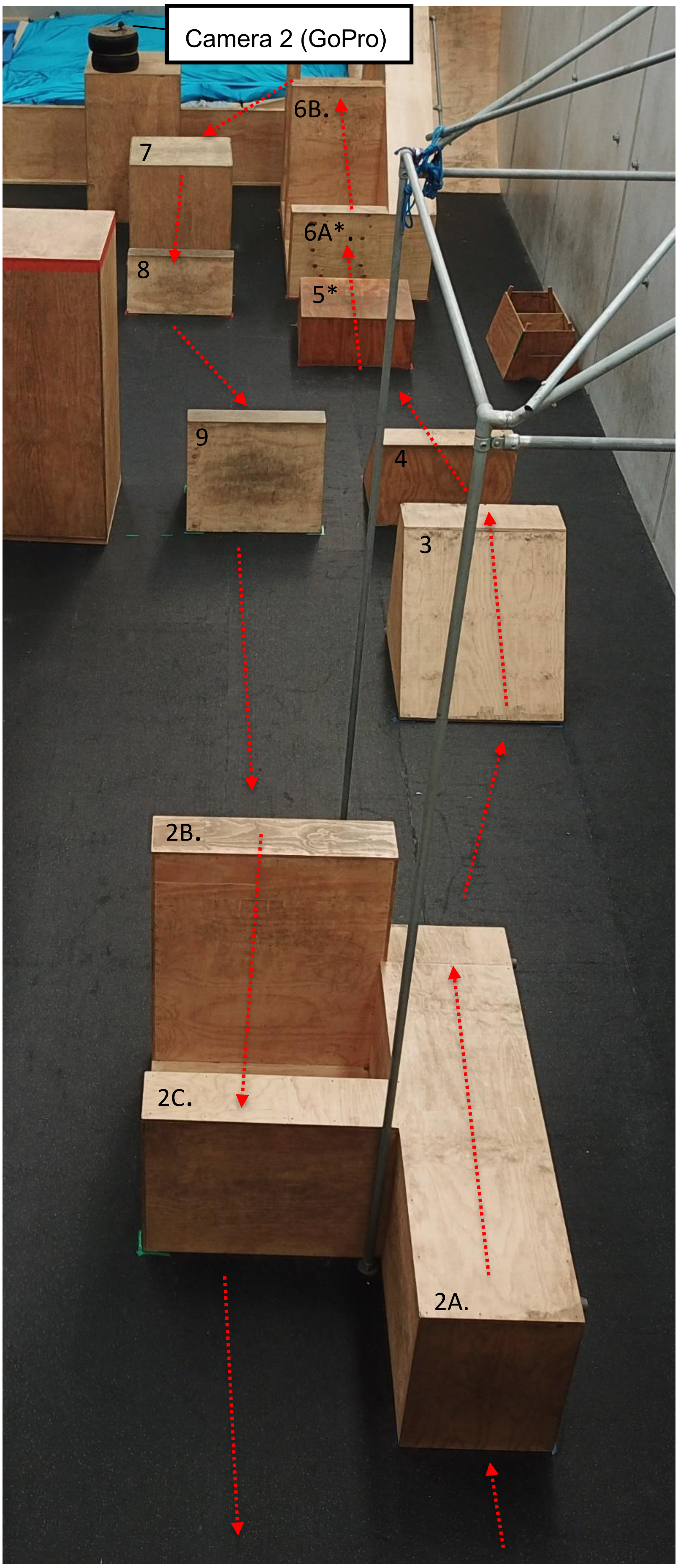


Figure 1 obstacle course layout
*Note. obstacle 5 and 6a in this diagram were excluded from analysis. Therefore, obstacle 5 in the results section refers to 6b-7.

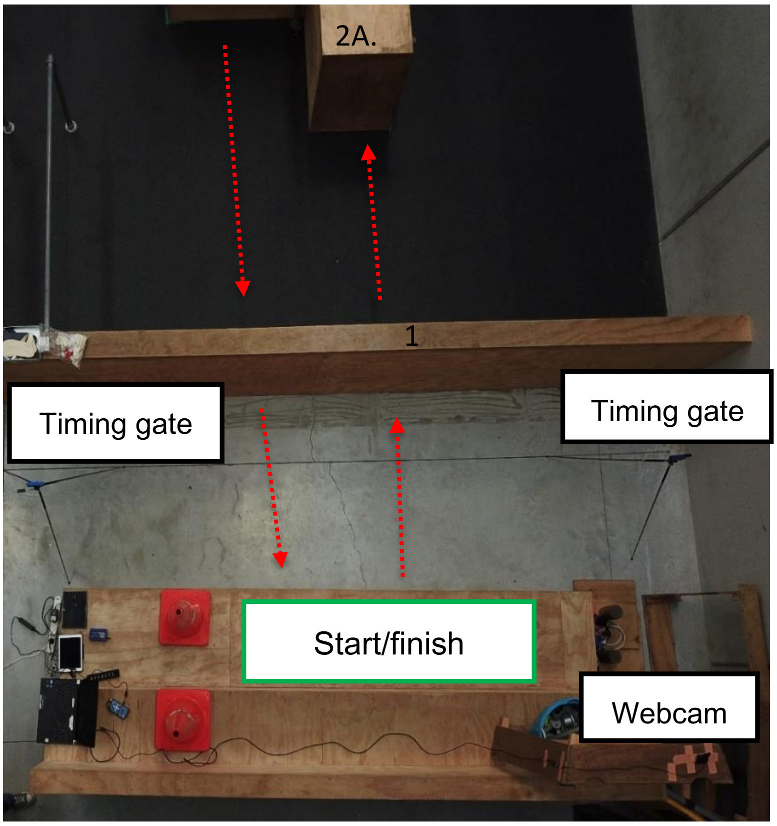


Figure 2 obstacle course layout (start and finish)

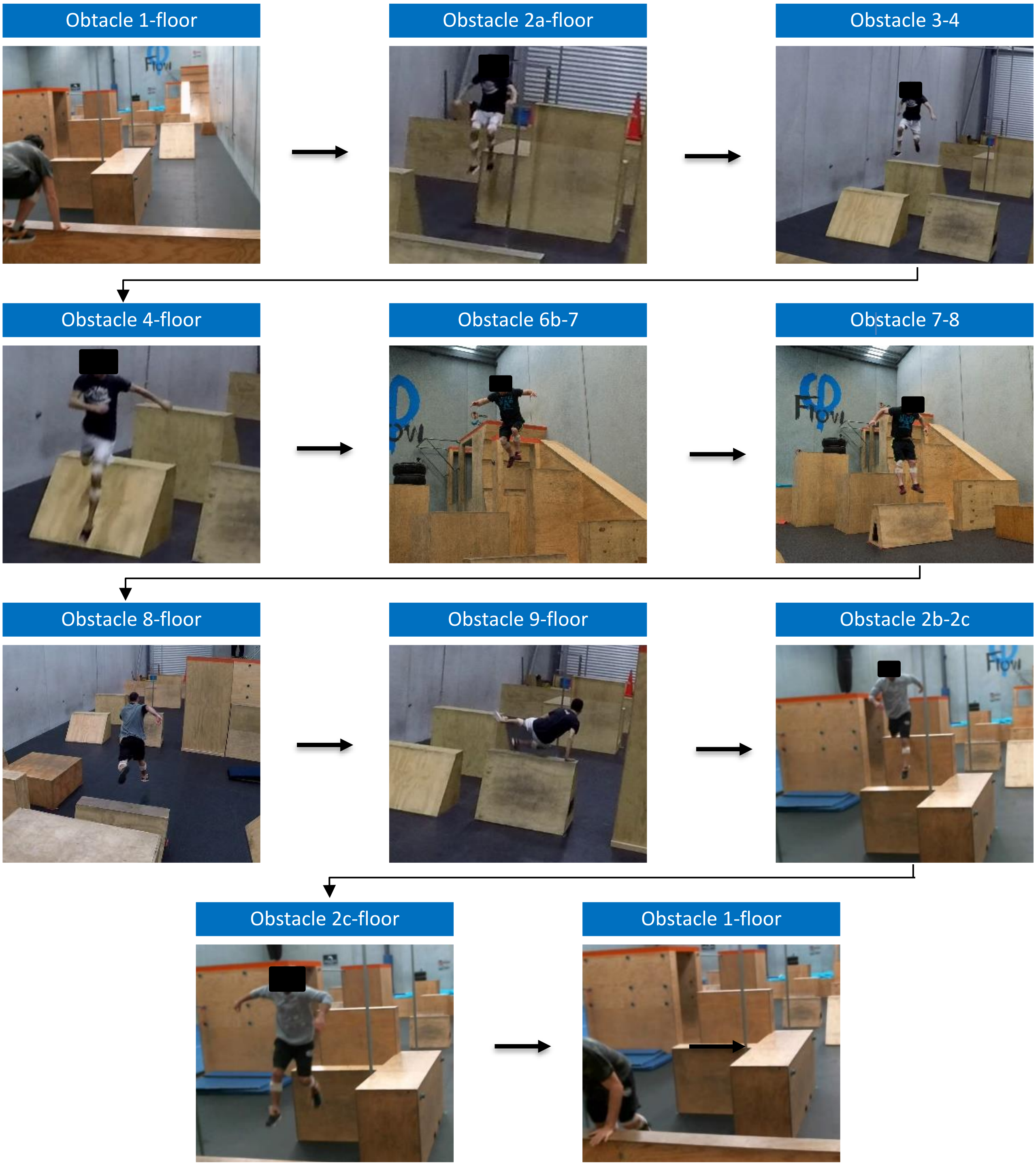


Figure 3 flow diagram showing obstacles and their associated landings used for analysis

**Data analysis**

A total of five trials from each participant were analysed in order to calculate the selected kinetic variables. For consistency, the limb with the greatest peak vGRF for each landing was used to extract force and EMG data during that landing. A total of 10 obstacle landings were used for both EMG and force data. Data from loadsol sensors were exported as a comma separated file into an excel datasheet (Microsoft, Inc; Bellevue, WA). Each obstacle landing was visually identified using GoPro data and the time was noted; the identified time was then matched to the time sequence within the insole datasheet. Peak vertical GRF, time to peak, and normalised force values were assessed for each landing. Peak vertical GRF was the largest value of vertical force during a single landing. The peak vertical GRF was identified for each foot and a bilateral comparison determined which side of the body would be assessed during that landing. To standardise all comparisons, the peak vertical GRF was normalised to bodyweight (N). Time to peak vertical GRF (ms) was calculated by subtracting the time at the recorded peak vertical GRF by the time at initial contact. Rate of force development (RFD) was identified by dividing the peak force (N) by the time to peak (s). All force variables were reported as mean values for each obstacle landing. EMG data was processed using Noraxon MRXP Master Edition, version 1.08.17 (Noraxon USA Inc., Scottsdale, AZ). The EMG signal was rectified and filtered using a bidirectional (zero lag) $8^{th}$ order Butterworth bandpass filter (10-500 Hz). EMG data was normalised and reported as a percentage of root mean square (RMS) by applying the appropriate MVIC to the corresponding muscle. Area under the amplitude curve was calculated for all obstacles and then exported to an excel datasheet (Microsoft, Inc; Bellevue, WA).

**Statistical analysis**

Means, standard deviations, and correlations were all calculated in SPSS (version 22, IBM Corporation, Armonk, NY) for all kinetic variables. Paired t-tests were used in SPSS to compare both force and EMG data between all obstacles. Effect sizes (Cohen's $d_z$) and post hoc power (β) analyses were calculated for all force and EMG variables. Kinetic variables were considered as statistically significant if they had values between p0.05 and β0.80.

## Results

Comparisons are presented if post hoc statistical power was appropriate (β>0.80) for variables of interest. Mean differences for comparisons (Table 2), as well as effect sizes and power (Table 3) for GRF, TTP, and RFD are displayed. All values identified within brackets refer to the mean difference between compared obstacles.

GRF data revealed that obstacle one had less GRF than both obstacles 7 (0.213 N/kg) and 8 (0.404 N/kg). Obstacle 2 produced a higher GRF than obstacle 9 (1.25 N/kg) and obstacle 3 had less force than obstacle 8 (-0.615 N/kg). Obstacle 4 had higher force than obstacle 6 (1.16 N/kg) and 9 (1.28N/kg). Obstacle 5 had less force than obstacle 8 (-0.479 N/kg). Obstacle 6 had less force than both obstacle 7 (-0.826 N/kg) and 8 (-0.931 N/kg). Obstacle 8 had greater force than obstacle 9 (1.05 N/kg). Obstacle 9 had less than obstacle 10 (-1.31 N/kg).

Obstacle one showed greater TTP than Obstacles 3 (30.5ms) and 10 (22.5ms), but lower than obstacle 7 (-38.50ms). Obstacle 3 had less TTP than obstacle 6 (-70.00ms). Obstacle 6 had greater TTP than obstacle 10 (65.25ms). No other comparisons reached appropriate power for TTP.

Obstacle 1 had a higher RFD than obstacle 5 (-6698.35N/s) and obstacle 9 (5588.08N/s) but less than obstacle 3 (-19780.73N/s), 8 (-4832.64N/s), and 10 (-25183.47N/s). Obstacle 2 had less RFD than obstacle 3 (-3101.14N/s). Obstacle 3 had higher RFD than obstacle 6 (26522.92N/s).

EMG recordings were also compared to better understand the mechanisms associated with differences in landing forces. Mean differences for EMG comparisons (table 3) as well as effect sizes and power (table 4) are displayed for VL, GM, and TA.  VL comparisons showed that obstacle 1 had a lower activation than obstacles 5 (-30.39mV), 6 (13.52mV), 8 (-12.54mV), and 9 (-15.76mV). Obstacle 2 showed a lower quadriceps activation than obstacle 5 (-21.81mV). Obstacle 3 had a lower quadriceps activation than obstacle 5 (-21.28mV) and 7 (-10.45mV). Obstacle 4 had a lower quadriceps activation than obstacle 5 (-18.69mV). Obstacle 5 had a lower quadriceps activation than obstacle 7 (12.67mV) and higher than obstacle 10 (25.28mV). Obstacle 6 had a greater quadriceps activation than obstacle 10 (17.60mV). Obstacle 7 had a greater activation than obstacle 10 (12.60mV).

GM comparisons revealed that obstacle one had a higher muscle activation than obstacle 3 (-4.90mV) and lower than 5 (-3.93mV). Obstacle 2 had a greater GM activation than obstacle 9 (7.78mV). Obstacle 3 had a higher GM activation than obstacle 9 (9.79mV) and obstacle 10 (10.64mV).

EMG comparisons for TA showed that obstacle one had a lower muscle activation than obstacle 5 (-8.62mV), and 8 (-13.61mV). obstacle 3 had a lower TA activation than obstacle 5 (-1.42mV) and obstacle 8 (-9.18mV). Obstacle 6 had a lower TA activation than obstacle 8 (-7.88mV).

Table 2. Mean (±SD) for force variables describing each obstacle.

| | **Obstacle #** | **Drop height (m)** | **Time to peak force (ms)** | **Peak RFD KN/s** | **mVF/BW** |
|---|---|---|---|---|---|
| 1 | 1-floor | 1.02 | 65.45±15.95 | 31,510.70±29007.13 | 2.49±0.44 |
| 2 | 2a-floor | 1.0 | 65.29±24.78 | 39,340.85±14,838.93 | 3.20±0.64 |
| 3 | 3-4 | 0.37 | 56±42.10 | 41,449.97±21,266.57 | 2.33±0.48 |
| 4 | 4-floor | 0.78 | 70±23.26 | 35,379.16±9,490.01 | 3.19±0.54 |
| 5 | 6b-7 | 0.75 | 67.5±21.24 | 29,082.02±9,633.28 | 2.47±0.34 |
| 6 | 7-8 | 0.59 | 126±46.04 | 14,927.04±9,529.68 | 2.02±0.21 |
| 7 | 8-floor | 0.65 | 100±35.53 | 25,454.38±16,636.87 | 2.84±0.33 |
| 8 | 9-floor | 0.90 | 67.22±26.75 | 38,600.17±21,625.06 | 2.97±0.31 |
| 9 | 2b-2c | 0.7 | 69.5±45.71 | 29,480.83±22,911.00 | 1.89±0.76 |
| 10 | 2c-floor | 1.0 | 61.58±30.23 | 46,522.81±21,783.78 | 3.20±0.52 |

Note. MVF: Maximal vertical force, BW: bodyweight, RFD: rate of force development

Table 3. Effect size and power values for comparisons of force variables that reached β>0.80

| Variable | Obstacle X | Obstacle Y | Effect Size | Power |
|---|---|---|---|---|
| Ground Reaction Force | 1 (1-floor) | 7 (8-floor) | -2.8 | .99 |
| | 1 (1-floor) | 8 (9-floor) | -2.3 | 0.95 |
| | 2 (2a-floor) | 9 (2b-2c) | 1.99 | 0.9 |
| | 3 (3-4) | 8 (9-floor) | -2.78 | 0.99 |
| | 4 (4-floor) | 9 (2b-2c) | 2.12 | 0.93 |
| | 4 (4-floor) | 6 (7-8) | 1.7 | 0.82 |
| | 5 (6b-7) | 8 (9-floor) | -3.3 | 0.99 |
| | 6 (7-8) | 7 (8-floor) | -2 | 0.92 |
| | 6 (7-8) | 8 (9-floor) | -2.57 | 0.98 |
| | 6 (7-8) | 10 (2c-floor) | -1.73 | 0.83 |
| | 8 (9-floor) | 9 (2b-2c) | 1.79 | 0.85 |
| | 9 (2b-2c) | 10 (2c-floor) | -2.05 | 0.92 |
| Time to Peak | 1 (1-floor) | 3 (3-4) | 14.38 | 1 |
| | 1 (1-floor) | 7 (8-floor) | -4.1 | 0.99 |
| | 1 (1-floor) | 10 (2c-floor) | 3.57 | 0.99 |
| | 3 (3-4) | 6 (7-8) | -1.95 | 0.89 |
| | 6 (7-8) | 10 (2c-floor) | 1.75 | 0.83 |
| | 7 (8-floor) | 8 (9-floor) | 1.74 | 0.83 |
| Rate of force development | 1 (1-floor) | 3 (3-4) | -1.79 | 0.85 |
| | 1 (1-floor) | 5 (6b-7) | -2.32 | 0.96 |
| | 1 (1-floor) | 8 (9-floor) | -2.21 | 0.94 |
| | 1 (1-floor) | 9 (2b-2c) | 1.95 | 0.89 |
| | 1 (1-floor) | 10 (2c-floor) | -2.29 | 0.95 |

Table 4. Mean (±SD) for electromyographic variables describing each obstacle

| | Obstacle # | Area %MVIC | | |
|---|---|---|---|---|
| | | VL | TA | GM |
| 1 | 1-floor | 25.13±13.74 | 16.01±4.83 | 37.36±16.49 |
| 2 | 2a-floor | 25.79±14.58 | 16.07±6.99 | 26.53±10.84 |
| 3 | 3-4 | 20.56±6.18 | 17.22±4.31 | 33.49±7.18 |
| 4 | 4-floor | 28.78±27.27 | 21.57±21.94 | 40.54±38.63 |
| 5 | 6b-7 | 47.30±13.91 | 21.90±8.63 | 39.83±22.89 |
| 6 | 7-8 | 39.97±16.12 | 18.84±9.74 | 37.34±26.94 |
| 7 | 8-floor | 34.45±8.41 | 20.44±9.50 | 32.81±16.70 |
| 8 | 9-floor | 34.81±16.89 | 26.39±5.40 | 30.93±14.50 |
| 9 | 2b-2c | 33.03±16.97 | 24.00±20.55 | 20.38±7.23 |
| 10 | 2c-floor | 22.49±12.93 | 15.05±5.46 | 19.38±7.33 |

Note. VL: vastus lateralis; GM: gastrocnemius; TA: tibialis anterior

Table 5. Effect size and power values for comparisons of electromyographic variables that reached β>0.80

| Variable | Obstacle X | Obstacle Y | Effect Size | Power |
|---|---|---|---|---|
| VL EMG | 1 (1-floor) | 5 (6b-7) | -3.15 | .99 |
| | 1 (1-floor) | 6 (7-8) | -2.32 | 0.96 |
| | 1 (1-floor) | 8 (9-floor) | -2.57 | 0.98 |
| | 1 (1-floor) | 9 (2b-2c) | -3.78 | 0.99 |
| | 2 (2a-floor) | 5 (6b-7) | -3.34 | 0.99 |
| | 3 (3-4) | 5 (6b-7) | -5.81 | 1 |
| | 3 (3-4) | 7 (8-floor) | -1.68 | 0.81 |
| | 5 (6b-7) | 7 (8-floor) | 1.65 | 0.8 |
| | 5 (6b-7) | 10 (2c-floor) | 4.12 | 0.99 |
| | 6 (7-8) | 10 (2c-floor) | 1.76 | 0.84 |
| | 7 (8-floor) | 10 (2c-floor) | 1.86 | 0.87 |
| GM EMG | 3 (3-4) | 9 (2b-2c) | 1.94 | 0.89 |
| | 3 (3-4) | 10 (2c-floor) | 1.75 | 0.83 |
| TA EMG | 1 (1-floor) | 2 (2a-floor) | 3 | 0.99 |
| | 1 (1-floor) | 5 (6b-7) | -2.4 | 0.96 |
| | 1 (1-floor) | 8 (9-floor) | -1.79 | 0.85 |
| | 3 (3-4) | 8 (9-floor) | -1.95 | 0.89 |

Note. VL: vastus lateralis; GM: gastrocnemius; TA: tibialis anterior

# Chapter 3

## Discussion

The purpose of the present study was to design a field-based protocol that measured and compared the ground reaction forces associated with a variety of parkour landings. Obstacle comparisons were made for peak vertical ground reaction force, time to maximal ground reaction force, and rate of force development. According to the force data, the highest GRF was associated with obstacles 2a-floor, 4-floor, and 2c-floor (table 2). Obstacle 2a, which was a large rectangular ledge, had one of the highest drop heights (table 2). Most participants simply stepped off the edge or performed a low vault off to the side to complete the obstacle. Additionally, as the distance between obstacle 2a and 3 was short, participants landed and quickly accelerated in order to run up the incline board on obstacle 3. Obstacle 4-floor also produced one of the highest GRF values. Both obstacles 3 and 4 were vault boxes with obstacle 4 being lower than obstacle 3. The most common method for overcoming this obstacle was jumping from the top of obstacle 3 to the top of obstacle 4 but only briefly landing on the top of obstacle 4. The brief contact time on obstacle 4 was likely due its narrow surface as well as participants trying to maintain their momentum in order to continue efficiently towards the next obstacle. The short time spent on obstacle 4 reduced the absorption phase and consequently produced one of the lowest force values. Therefore, the forces associated with 4-floor which were among the highest, were more of a combination of obstacle 3-4 and 4-floor. Similarly, the higher forces associated with obstacle 2c-floor may be due to participants jumping from 2b with only a short contact time on obstacle 2c. Again, obstacle 2b-2c had one of the lowest forces suggesting that the forces observed with 2c-floor were summative of 2b-2c and 2c-floor.

Ground reaction force plays a significant role in most sports as it quantifies the magnitude of stress placed upon the body (10). The accumulation of high impact forces may have harmful effects on the lower extremities, which may lead to injury (55). Although few studies have looked at GRF in parkour there is an abundance of research looking into more common landing movements. For example, peak vertical GRF during single leg landing from a somersault in gymnasts have been reported at values as high as 14.4 times bodyweight (22). Stacoff et al. (30) reported GRF associated with landing after a volleyball block jump had peak values of up to 6000 Newtons (N). Previous research using standardised drop landing protocols have observed ground reaction forces between 4-9 times bodyweight (4, 19, 34). In comparison to previous parkour research, the forces associated with obstacles 2a-floor, 4-floor, and 2c-floor were similar to the findings of Puddle and Maulder who reported landing forces of 3.2 mVF/BW during precision landings at a height of 0.75m (53). Standing and Maulder, who also investigated the forces associated with parkour landings, found that experienced tracers produced forces of up to 3.6 mVF/BW while landing from a platform set to 50% body height (63). It is important to note, however, that the forces measured in both parkour studies, as well as in the non-parkour landing research, involved participants coming to either a complete stop or a prolonged landing phase. However, no participants came to a complete stop during landings in this study. The differences between static and dynamic landings are an important consideration as a typical parkour landing involves an ever-changing combination of variables such as speed, agility, and multiple movement skills that in turn may affect the forces placed on the body. The forces observed in the current study were lower than most of the previous research and similar to the parkour studies. The lower landing forces measured in previous parkour studies may be due to several factors however: it appears that landing technique plays a major role (36, 53, 63). Specifically, kinematic variables such as greater trunk, hip, knee, and ankle flexion, which are commonly seen in the precision landing, have been shown to reduce ground reaction force. Unfortunately, joint kinematics were beyond the scope of the current study.

Time to peak GRF has also been considered an influential factor when investigating GRF as an increased amount of time requires less force to generate the braking momentum needed in landing (14, 15). In the current study obstacles 3-4, 2c-floor, 2a-floor, and 1-floor produced the lowest time to peak values (table 2). As mentioned, participants contact time on obstacle 3-4 was short which may be due to participants trying to preserve momentum. In turn this reduced contact time may have limited the time the muscles had to absorb additional force. Furthermore, due to limited space around obstacles 2a-floor, 2c-floor, and 1-floor, participants had to accelerate immediately upon landing in order to complete subsequent obstacles. As a result, 2a-floor, 2c-floor, and 1-floor all had higher GRF as well as some of the lowest TTP values.

The previous research by Puddle and Maulder reported mean time to peak values of 77ms for the precision landing at 0.75m and Standing and Maulder reported mean time to peak values of 56ms in traceurs performing a drop landing at 50% body height. The values observed in the current study were slightly lower than those of Puddles but were similar to those found by Standing and Maulder. Again, it is important to note that the current study used dynamic landings compared to static, and the added speed and acceleration may affect both the GRF and TTP. Interestingly, obstacles 7-8 and 8-floor had the highest TTP values. The landings from both these obstacles involved participants quickly descending from 7-8 and 8-floor before accelerating towards obstacle 9. The higher TTP may have been necessary for the body to make a change in momentum without increasing the forces placed on the body.

Rate of force development is an important factor in developing muscular power and is considered a key determinant in sport performance (13, 16). Obstacle 2a-floor, 3-4, 4-floor, 9-floor, and 2c-floor produced the highest RFD values (table 2). As stated, 2a-floor involved participants landing and quickly accelerating towards obstacle 3 and obstacle 4 had a short contact time. Similarly, due to limited space around obstacle 4-floor participants quickly landed from obstacle 4-foor and immediately jumped or stepped onto the next obstacle. Obstacle 9-floor involved performing a vault and quickly running to obstacle 2b, which was a low climbing wall. As mentioned, obstacle 2c-floor involved a higher GRF, lower TTP, and required a fast jump in order to clear obstacle 1. The above-mentioned landings all required brief contact time as well as explosive power in order to overcome subsequent obstacles, which help explain the higher RFD values. Unfortunately, no studies were identified that specifically investigated RFD in parkour landings. However, research on more common jumping movements has shown lower RFD values than what has been presented in this study (28). The higher RFD values in the current study may again be due to the dynamic nature of the parkour course which included several obstacles being completed consecutively at speed.

The muscular system plays a significant role in attenuating the mechanical stress placed on the body during landing (29). The muscles act as shock absorbers by dissipating kinetic energy during landing and other deceleration movements (31). Muscle activity was recorded to further understand the underlying mechanisms involved in each obstacle landing (table 4). According to the literature, both the knee flexors and ankle plantar flexors must contract eccentrically in order to dissipate the additional stress during landing (4). Both the VL and GM showed higher activations on obstacles requiring high levels of deceleration. For example, 6b-7 required rapid deceleration as well as a pivot in order to change direction for obstacle 8. Additionally, the descent from 7-8 and 8-floor required control and momentum preserved in order to complete obstacle 9-floor. As mentioned, the forces associated with obstacles 7-8 and 8-floor were slightly lower while also having the highest TTP values. The moderate forces, higher TTP and higher levels of VL and GM activation suggests these muscles may have been working to reduce the forces produced during the deceleration on these obstacles. TA showed higher activations on obstacle 9-floor and 2b-2c but activations were similar across most obstacles. The activation of the TA may be due to its role in eccentrically contracting during initial foot strike during landing (12, 34).

Unfortunately, muscular activity during parkour landings is scarce. One study by Maldanado et al. (36), however, measured lower limb kinematics, dynamics, and energetics in parkour landings and reported that the knee extensors played a crucial role in energy dissipation during landings. Kellis and Kouvelioti (29) who measured lower limb EMG activity during a box drop task reported that an increase in knee flexion during landing was associated with greater activation of the knee extensors as well as reduced GRF. Although these studies help explain the kinematics and kinetics involved in landings, more research is needed to understand the links between kinetic and kinematic variables in parkour.

The current study had several limitations that should be mentioned. The field-based approach had several unanticipated difficulties that resulted in a smaller sample size than expected. However, with the sample used, several significant comparisons and observations were made. The force insoles used in this study were only capable of measuring vertical forces. Participants would have been exposed to both vertical and anterior-posterior forces during all landings and therefore it is an important consideration for future research. Likewise, due to the high speeds, short contact time, and obstacle proximity, it is likely that the forces measured during landing may have also included propulsion forces. Natural parkour movements were a key factor for this study and therefore no instructions were given for how participants were to complete each obstacle. However, it is important to note that this approach resulted in a variety of movements and landing techniques which may affect the forces and EMG recordings on each obstacle.

## Conclusion

The current study investigated and compared the ground reaction forces associated with several parkour landings. The field-based approach allowed a close representation of the forces exposed to a parkour athlete in their natural training environment. In this study, the highest forces were associated with obstacles requiring immediate acceleration upon landing as well as landings involving greater momentum from previous obstacles. Lowest TTP values were associated with obstacles that had limited contact time due to participants preserving momentum or involving narrow surfaces. RFD was greatest on obstacles requiring greater levels of acceleration. In addition, EMG showed that the GM and VL had the greatest activations on obstacles requiring deceleration as well as control or change of momentum. It was observed that all the above factors played a crucial role in the ability of athletes to complete the course. Furthermore, kinematic variables such as landing technique and movement skill would have also played an important part. Although beyond the scope of the current study, future research should aim to investigate both kinematic and kinetic factors in order to provide a greater understanding of parkour performance and injury prevention.

# Appendix

## Ethics approval

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Date: 15 December 2017

Dear Marcel Austmann

Re: Ethics Notification - **SOA 17/60 - A comparison of novice versus experienced traceurs and their associated ground reaction forces and electromyography in a parkour obstacle course**

Thank you for the above application that was considered by the Massey University Human Ethics Committee: **Human Ethics Southern A Committee** at their meeting held on **Friday, 15 December, 2017**.

On behalf of the Committee I am pleased to advise you that the ethics of your application are approved.

Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

Dr Brian Finch
Chair, Human Ethics Chairs' Committee and Director (Research Ethics)

**Research Ethics Office, Research and Enterprise**
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand **T** 06 951 6841; 06 95106840
**E** humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz

## Consent form

Name: ______________________________ Age: _____________ DOB: ___________ Gender: _________

Email: ____________________________________________ Preferred contact number: ______________

| | | |
|---|---|---|
| I have read the information sheet for this study and understand the purpose, objectives, as well as what is required as a participant. | Yes ☐ | No ☐ |
| I understand that taking part in this study is voluntary and that I may withdraw from the study at any time without consequences | Yes ☐ | No ☐ |
| If I decide to withdraw from the study, I agree that the information collected about me up to the point when I withdraw may still be used for analysis | Yes ☐ | No ☐ |
| I consent to the researcher collecting and processing my health information, including height, bodyweight, as well as any health conditions obtained in the questionnaire. | Yes ☐ | No ☐ |
| I understand that this parkour experiment will involves a variety of movements and obstacles and as such there may be an increased chance of injury | Yes ☐ | No ☐ |
| I agree to the use of video recording during testing and have been made aware that my identity will not be compromised. | Yes ☐ | No ☐ |
| I understand that my participation in this study is confidential and that no material which could identify me personally, will be used in any reports or publications | Yes ☐ | No ☐ |
| I understand that data may be used in a presentation and that only group averages will be used. | Yes ☐ | No ☐ |
| I wish to receive a summary of the results of this study | Yes ☐ | No ☐ |

**Please read each statement carefully and tick to indicate you consent to the following**

**Declaration by participant:**

I hereby consent to take part in this study.

Participant's name:

---

Signature: Date:

---

**Declaration by researcher**

I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Researcher's name:

---

Signature: Date:

---

## Health and physical activity questionnaire

The purpose of this questionnaire is to identify any health issues or concerns that may place you at risk during exercise. Please read each question carefully and answer them to the best of your knowledge. The information you provide will be treated as confidential and only accessible by the researcher and supervisor.

**Participant Details**

Name: ______________________________ Age: _____________ DOB: ___________ Gender: _________

Email: ____________________________________________ Preferred contact number: ______________

Address: ____________________________________________ Occupation: _________________________

How would you prefer to be contacted? Email ☐ Text ☐ Phone call ☐ Other: _____________

Other information: _______________________________________________________________________

**Physical Activity Readiness Questionnaire**

| **Please read the questions carefully and answer each one honestly: check YES or NO.** | ☑ |
|---|---|
| 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? | Yes ☐<br>No ☐ |
| 2. Do you feel pain in your chest when you do physical activity? | Yes ☐<br>No ☐ |
| 3. In the past month, have you had chest pain when you were not doing physical activity? | Yes ☐<br>No ☐ |
| 4. Do you lose your balance because of dizziness or do you ever lose consciousness? | Yes ☐<br>No ☐ |
| 5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity? | Yes ☐<br>No ☐ |
| 6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? | Yes ☐<br>No ☐ |
| 7. Do you know of any other reason why you should not do physical activity? | Yes ☐<br>No ☐ |

Taken from Canadian Society for Exercise Physiology

**Do you have any recent (within the last 6 months) lower limb injuries that required medical attention** Yes ☐ No ☐

If yes, please provide detail below on what happened.

______________________________________________________________________________

______________________________________________________________________________

**Did this injury require surgery?** Yes ☐ No ☐

If yes, please provide detail below.

______________________________________________________________________________

______________________________________________________________________________

**Is there anything not mentioned in this questionnaire that you think may affect your ability to perform exercise in a safe manner?** Yes ☐ No ☐

If yes, please explain: ____________________________________________________________

**Parkour training experience**

How many months or years of parkour specific training do you have? _____________

On average, how many days per week would you spend training for parkour? _____________

Approximately how long would a typical parkour session last? _____________

Have you been involved in any parkour training classes? Yes ☐ No ☐

If yes, please detail below the total duration (months/years) and aim of the class

______________________________________________________________________________

______________________________________________________________________________

Do you feel confident in your ability to perform fundamental skills in parkour such as landing, basic vaults, and climbing? Yes ☐ No ☐

**On the scale below, where would you rate your current parkour experience level?** _____

| Novice | Good | Experienced | Highly experienced | Elite |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Other physical activity**

**Are you involved in any other forms of physical activity?** Yes ☐ No ☐

If yes, please detail below what other activities you are involved in and how much time you would spend on these activities each week. For example, running, 30 minutes, 3 times per week.

| Activity | Duration of activity | Number of sessions per week |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Please return the completed form to:
Marcel Austmann
PH: 02102706910
Email: static_motion@hotmail.com

## Bibliography


1. **Abbott BC**, **Aubert XM**, **Hill AV**. The absorption of work when a muscle is stretched. *The Journal of Physiology* 111: 41p–2p, 1950.

2. **Aggerholm K**, **Højbjerre Larsen S**. Parkour as acrobatics: an existential phenomenological study of movement in parkour. *Qualitative Research in Sport, Exercise and Health* 9: 69–86, 2017.

3. **Ameel L**, **Tani S**. Everyday aesthetics in action: Parkour eyes and the beauty of concrete walls. *Emotion, Space and Society* 5: 164–173, 2012.

4. **Andrews JR**, **McLeod WD**, **Ward T**, **Howard K**. The cutting mechanism. *The American Journal of Sports Medicine* 5: 111–121, 1977.

5. **Angel JM**. Ciné Parkour: A cinematic and theoretical contribution to the understanding of the practice of parkour [Online]. Brunel University School of Arts PhD Theses: 2011. The cutting mechanism [11 Oct. 2018].

6. **Arampatzis A**, **Morey-Klapsing G**, **Brüggemann G-P**. The effect of falling height on muscle activity and foot motion during landings. *Journal of Electromyography and Kinesiology* 13: 533–544, 2003.

7. **Bavinton N**. From obstacle to opportunity: Parkour, leisure, and the reinterpretation of constraints. *Annals of leisure research* 10: 391–412, 2007.

8. **Blackburn JT**, **Padua DA**. Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clinical Biomechanics* 23: 313–319, 2008.

9. **Blanco M**, **Lee D**. Foot pain after parkour in a 31-year-old man. *The Journal of Musculoskeletal Medicine* 28: 21–22, 2011.

10. **Butler RJ**, **Crowell HP**, **Davis IM**. Lower extremity stiffness: implications for performance and injury. *Clinical Biomechanics (Bristol, Avon)* 18: 511–517, 2003.

11. **Campbell A**, **Kemp-Smith K**, **O'Sullivan P**, **Straker L**. Abdominal Bracing Increases Ground Reaction Forces and Reduces Knee and Hip Flexion During Landing. *The Journal of Orthopaedic and Sports Physical Therapy* 46: 286–292, 2016.

12. **Christina KA**, **White SC**, **Gilchrist LA**. Effect of localized muscle fatigue on vertical ground reaction forces and ankle joint motion during running. *Human Movement Science* 20: 257–276, 2001.

13. **Comfort P**, **Fletcher C**, **McMahon JJ**. Determination of Optimal Loading During the Power Clean, in Collegiate Athletes: *Journal of Strength and Conditioning Research* 26: 2970–2974, 2012.

14. **Cortes N**, **Morrison S**, **Van Lunen BL**, **Onate JA**. Landing technique affects knee loading and position during athletic tasks. *Journal of Science and Medicine in Sport* 15: 175–181, 2012.

15. **Cortes N**, **Onate J**, **Abrantes J**, **Gagen L**, **Dowling E**, **Van Lunen B**. Effects of gender and foot-landing techniques on lower extremity kinematics during drop-jump landings. *Journal of Applied Biomechanics* 23: 289, 2007.

16. **Cronin J**, **McNair PJ**, **Marshall RN**. Developing explosive power; a comparison of technique and training. *Journal of Science & Medicine in Sport* 4: 59–70, 2001.

17. **D Beynnon B**, **M Vacek P**, **Murphy D**, **Alosa D**, **Paller D**. First-Time Inversion Ankle Ligament Trauma: The Effects of Sex, Level of Competition, and Sport on the Incidence of Injury. *The American Journal of Sports Medicine* 33: 1485–91, 2005.

18. **Derakhshan N**, **Machejefski T**. Distinction between parkour and freerunning. *Chinese Journal of Traumatology* 18: 124, 2015.

19. **Derakhshan N**, **Zarei MR**, **Malekmohammady Z**, **Rahimi-Movaghar V**. Spinal cord injury in Parkour sport (free running): a rare case report. *Chinese Journal of Traumatology* 17: 178–179, 2014.

20. **Devita P**, **Skelly WA**. Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise* 24: 108–115, 1992.

21. **Devita P**, **Skelly WA**. Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise* 24: 108–115, 1992.

22. **Dvořák M**, **Baláš J**, **Martin A**. The Reliability of Parkour Skills Assessment. *Sports* 6: 6, 2018.

23. **Frumkin K**. Bilateral Calcaneal Fractures and “Free Running”: A Dangerously Cool Emerging “Sport.” *Annals of Emergency Medicine* 46: 300, 2005.

24. **Grosprêtre S( 1 2 )**, **Lepers R( 1 2 )**. Performance characteristics of Parkour practitioners: Who are the traceurs? *European Journal of Sport Science* 16: 526–535, 2016.

25. **Harrison P. I Crowell, A. Treadwell T**, **A. Faughn J**, **L. Leiter K**, **A. Woodward A**. Lower Extremity Assistance for Parachutist (LEAP) Program. Quantification of the Biomechanics of the Parachute Landing Fall and Implications for a Device to Prevent Injuries. 137, 1995.

26. **Hermens HJ**, **Freriks B**, **Disselhorst-Klug C**, **Rau G**. Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology* 10: 361–374, 2000.

27. **Hewit J**, **Cronin J**, **Button C**, **Hume P**. Understanding deceleration in sport. *Strength & Conditioning Journal* 33: 47–52, 2011.

28. **Kawamori N**, **Rossi SJ**, **Justice BD**, **Haff EE**, **Pistilli EE**, **O’Bryant HS**, **Stone MH**, **Haff GG**. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *Journal of Strength and Conditioning Research* 20: 483–491, 2006.

29. **Kellis E**, **Kouvelioti V**. Agonist versus antagonist muscle fatigue effects on thigh muscle activity and vertical ground reaction during drop landing. *Journal of Electromyography and Kinesiology* 19: 55–64, 2009.

30. **Kidder JL**. Parkour: Adventure, Risk, and Safety in the Urban Environment. *Qualitative Sociology* 36: 231–250, 2013.

31. **Lafortune MA**, **Lake MJ**, **Hennig EM**. Differential shock transmission response of the human body to impact severity and lower limb posture. *Journal of Biomechanics* 29: 1531–1537, 1996.

32. **LaStayo PC**, **Woolf JM**, **Lewek MD**, **Snyder-Mackler L**, **Reich T**, **Lindstedt SL**. Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. *Journal of Orthopaedic & Sports Physical Therapy* 33: 557–571, 2003.

33. **Leporace G**, **Praxedes J**, **Pereira GR**, **Chagas D**, **Pinto S**, **Batista LA**. Activation of hip and knee muscles during two landing tasks performed by male volleyball athletes. *Revista Brasileira de Medicina do Esporte* 17: 324–328, 2011.

34. **Lichtwark G**. The role of the tibialis anterior muscle and tendon in absorbing energy during walking. *Journal of Science and Medicine in Sport* 18: e129, 2014.

35. **Lindstedt SL**, **LaStayo PC**, **Reich TE**. When active muscles lengthen: properties and consequences of eccentric contractions. *Physiology* 16: 256–261, 2001.

36. **Maldonado G**, **Soueres P**, **Watier B**. Strategies of Parkour practitioners for executing soft precision landings. *Journal of Sports Sciences* 36: 2551–2557, 2018.

37. **Marchetti PH**, **Junior DAL**, **Soares EG**, **Silva FH**, **Uchida MC**, **Teixeira LFM**. Differences in muscular performance between practitioners and non practitioners of Parkour. *International Journal of Sports Science* 2: 36–41, 2012.

38. **Masters C**, **Johnstone J**, **Hughes G**. The Effect of Arm Position on Lower Extremity Kinematics during a Single Limb Drop Landing: A Preliminary Study. *Journal of Functional Morphology and Kinesiology* 1: 282–288, 2016.

39. **McClay IS**, **Robinson JR**, **Andriacchi TP**, **Frederick EC**, **Gross T**, **Martin P**, **Valiant G**, **Williams KR**, **Cavanagh PC**. A Profile of Ground Reaction Forces in Professional Basketball. *Journal of Applied Biomechanics* 10: 222–236, 1994.

40. **McLean CR**, **Houshian S**, **Pike J**. Paediatric fractures sustained in Parkour (free running). *Injury* 37: 795–797, 2006.

41. **MCNITT G-J**. Kinetics of the lower extremities during drop landings from three heights (Cinetique des membres inferieurs lors de la reception de sauts en profondeur a partir de trois hauteurs.). *Journal of Biomechanics* 26: 1037–1046, 1993.

42. **McNitt-Gray JL**. The influence of impact speed on joint kinematics and impulse characteristics of drop landings. *Journal of Biomechanics* 22: 1054, 1989.

43. **Miller JR**, **Demoiny SG**. Parkour: A New Extreme Sport and a Case Study. *The Journal of Foot and Ankle Surgery* 47: 63–65, 2008.

44. **Miyasaka KC**, **Daniel DM**, **Stone ML**, **P H**. The incidence of knee ligament injuries in the general population. *The American Journal of Knee Surgery* 4: 3–8, 1991.

45. **Niu W**, **Feng T**, **Jiang C**, **Zhang M**. Peak vertical ground reaction force during two-leg landing: A systematic review and mathematical modeling. *BioMed Research International*, 2014.

46. **O'Loughlin A**. A door for creativity – art and competition in parkour [Online]. *Theatre, Dance and Performance Training*. [11 Oct. 2018].

47. **Palmieri-Smith R**, **Kreinbrink J**, **Ashton-Miller J**, **M Wojtys E**. Quadriceps Inhibition Induced by an Experimental Knee Joint Effusion Affects Knee Joint Mechanics During a Single-Legged Drop Landing. *The American Journal of Sports Medicine* 35: 1269–1275, 2007.

48. **Pandy MG**, **Zajac FE**, **Sim E**, **Levine WS**. An optimal control model for maximum-height human jumping. *Journal of Biomechanics* 23: 1185–1198, 1990.

49. **Panzer VP**, **Wood GA**, **Bates BT**, **Mason BR**. Lower extremity loads in landings of elite gymnasts. *Biomechanics XI-B* 10: 727–735, 1988.

50. **Peebles A**, **Maguire L**, **Renner K**, **Queen R**. Validity and Repeatability of Single-Sensor Loadsol Insoles during Landing. *Sensors* 18: 4082, 2018.

51. **Pollard CD**, **Sigward SM**, **Powers CM**. Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clinical Biomechanics* 25: 142–146, 2010.

52. **Proske U**, **Morgan DL**. Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology* 537: 333–345, 2001.

53. **Puddle DL**, **Maulder PS**. Ground reaction forces and loading rates associated with parkour and traditional drop landing techniques. *Journal of Sports Science & Medicine* 12: 122, 2013.

54. **Radin EL**. The effects of repetitive loading on cartilage. Advice to athletes to protect their joints. *Acta Orthopaedica Belgica* 49: 225–232, 1982.

55. **Radin EL**, **Parker HG**, **Pugh JW**, **Steinberg RS**, **Paul IL**, **Rose RM**. Response of joints to impact loading—III: Relationship between trabecular microfractures and cartilage degeneration. *Journal of Biomechanics* 6: 51–54, 1973.

56. **Radin EL**, **Yang KH**, **Riegger C**, **Kish VL**, **O'Connor JJ**. Relationship between lower limb dynamics and knee joint pain. *Journal of orthopaedic research* 9: 398–405, 1991.

57. **Raszeja N**, **Anderson K**, **McInnis T**, **Bailey C**. Ground reaction force analysis in football blocking. *Unpublished* (2016). doi: 10.13140/rg.2.2.14433.10082.

58. **Roberts TJ**, **Azizi E**. Flexible mechanisms: the diverse roles of biological springs in vertebrate movement. *Journal of Experimental Biology* 214: 353–361, 2011.

59. **Rossheim ME**, **Stephenson CJ**. Parkour injuries presenting to United States emergency departments, 2009–2015. *The American Journal of Emergency Medicine* ( April 2017). doi: 10.1016/j.ajem.2017.04.040.

60. **Seegmiller JG**, **McCaw ST**. Ground reaction forces among gymnasts and recreational athletes in drop landings. *Journal of Athletic Training* 38: 311, 2003.

61. **Slater A**, **Campbell A**, **Smith A**, **Straker L**. Greater lower limb flexion in gymnastic landings is associated with reduced landing force: a repeated measures study. *Sports Biomechanics* 14: 45–56, 2015.

62. **Stacoff A**, **Kaelin X**, **Stuessi E**. The impact in landing after a volleyball block. *Biomechanics XI-B* 694–700, 1988.

63. **Standing RJ**, **Maulder PS**. A Comparison of the Habitual Landing Strategies from Differing Drop Heights of Parkour Practitioners (Traceurs) and Recreationally Trained Individuals. *Journal of Sports Science & Medicine* 14: 723, 2015.

64. **Suda EY**, **Amorim CF**, **de Camargo Neves Sacco I**. Influence of ankle functional instability on the ankle electromyography during landing after volleyball blocking. *Journal of Electromyography and Kinesiology* 19: e84–e93, 2009.

65. **Vivanco-Allende A**, **Concha-Torre A**, **Menéndez-Cuervo S**, **Rey-Galán C**. Parkour: una nueva causa de lesiones internas graves. *Anales de Pediatría* 79: 396–397, 2013.

66. **Wernli K**, **Ng L**, **Phan X**, **Davey P**, **Grisbrook T**. The Relationship Between Landing Sound, Vertical Ground Reaction Force, and Kinematics of the Lower Limb During Drop Landings in Healthy Men. *The Journal of Orthopaedic and Sports Physical Therapy* 46: 194–199, 2016.

67. **Whitting JW**, **Steele JR**, **Jaffrey M**, **Munro BJ**. Does foot pitch at ground contact affect parachute landing technique? *Military Medicine* 174: 832–837, 2009.

68. **Xia R**, **Zhang X**, **Wang X**, **Sun X**, **Fu W**. Effects of Two Fatigue Protocols on Impact Forces and Lower Extremity Kinematics during Drop Landings: Implications for Noncontact Anterior Cruciate Ligament Injury. *Journal of Healthcare Engineering*: 2017.

69. **Yu B**, **Lin C-F**, **Garrett WE**. Lower extremity biomechanics during the landing of a stop-jump task. *Clinical Biomechanics* 21: 297–305, 2006.

70. **Zhang S**, **Derrick TR**, **Evans W**, **Yu Y-J**. Shock and impact reduction in moderate and strenuous landing activities. *Sports Biomechanics* 7: 296–309, 2008.

71. **Zhang S-N**, **Bates BT**, **Dufek JS**. Contributions of lower extremity joints to energy dissipation during landings. *Medicine and Science in Sports and Exercise* 32: 812–819, 2000.