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Research article

A Comparison of the Habitual Landing Strategies from Differing Drop Heights of Parkour Practitioners (Traceurs) and Recreationally Trained Individuals

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Abstract
Parkour is an activity that encompasses methods of jumping, climbing and vaulting. With landing being a pertinent part of this practise, Parkour participants (traceurs) have devised their own habitual landing strategies, which are suggested to be a safer and more effective style of landing. The purpose of this study was to compare the habitual landing strategies of traceurs and recreationally trained individuals from differing drop heights. Comparisons between landing sound and mechanical parameters were also assessed to gauge the level of landing safety. Ten recreationally trained participants and ten traceurs performed three landings from 25% and 50% body height using their own habitual landing strategies. Results at 25% showed significantly lower maximal vertical force (39.9%, $p < 0.0013$, ES = -1.88), longer times to maximal vertical force (68.6%, $p < 0.0015$, ES = 1.72) and lower loading rates (65.1%, $p < 0.0002$, ES = -2.22) in the traceur group. Maximal sound was also shown to be lower (3.6%), with an effect size of -0.63, however this was not statistically significant ($p < 0.1612$). At 50%, traceurs exhibited significantly different values within all variables including maximal sound (8.6%, $p < 0.03$, ES = -1.04), maximal vertical force (49.0%, $p < 0.0002$, ES = -2.38), time to maximal vertical force (65.9%, $p < 0.0067$, ES = 1.32) and loading rates (66.3%, $p < 0.0002$, ES = -2.00). Foot strike analysis revealed traceurs landed using forefoot or forefoot-midfoot strategies in 93.2% of trials; whereas recreationally trained participants used these styles in only 8.3% of these landings. To conclude, the habitual landings of traceurs are more effective at lowering the kinetic landing variables associated with a higher injury risk in comparison to recreationally trained individuals. Sound as a measure of landing effectiveness and safety holds potential significance; however requires further research to confirm.

Key words: Kinetics, forefoot, Parkour, dissipation, kinematics.

Introduction

Parkour is a form of acrobatic street gymnastics which was originally established in France. Over the past 10 years participation has compounded and the practise has emerged in countries all over the world (Atkinson, 2009). Parkour requires the participants (known as traceurs) to use a creative approach and a vast, all-encompassing variety of skills to overcome obstacles in pseudo, or real-world urban settings (Archer, 2010). These skills often include, but are not limited to vaulting, climbing, jumping and variations of athletic agility.

With many of these skills, there is a portion of the movement that requires a transitional or endpoint landing phase. The ability to perform safe landing strategies consistently is critical for minimising the risk of injuries and in turn increasing the longevity of a traceurs Parkour career. In typical everyday life, different landing strategies are often used to accomplish movement objectives such as human locomotion (Kovacs et al., 1999) and jumping (McNair and Prapavessis, 1999; Tillmanet al., 2004), with the mechanics of these landings varying depending on pertinent factors which include the landing surface (McNitt-Gray et al., 1994), velocity of impact (Horita et al, 2002) and relevant mass of the individual (Wikstrom et al., 2006). In higher paced environments such as court sports, incorrect landing technique has been stated to be the leading cause of injuries to both the knee and ankle (Hume and Steele, 2000).

When any style of landing occurs, whether it be in a leisure or sporting based environment, a degree of ground reaction force (GRF) is encountered (McNair, 2010). These GRFs provide an indication of the magnitude and duration of the stress the body is exposed to during the landing phase of a movement (Bressel and Cronin, 2005; McClay et al., 1994). GRFs can be measured in the vertical, anterior-posterior (horizontal), or medial-lateral (side to side) directions; however the majority of landing literature is concerned with the vertical and horizontal force applications (Bisseling et al., 2008; Butler et al., 2003; Elvin et al., 2007). If the magnitude of GRFs encountered during a landing is too great and the musculoskeletal system is unable to disperse the forces effectively then the probability of injury occurring increases dramatically (Bressel and Cronin, 2005; Irmischer et al., 2004). This likelihood of injury is compounded when there is a high rate at which these GRFs impact the body (loading rate), due to shock absorption and force distribution through the joints, muscles and ligaments involved with the movement (Bauer et al., 2001; Cortes et al., 2007). The findings of this past research proves the importance of utilising the safest possible landing strategy, especially when moving at high pace, during sudden stops, or during changes of direction, as seen in Parkour.

Research has identified two main styles of landing that are used commonly amongst both athletic and non-athletic populations. The first strategy acknowledged is the heel-toe (rear-foot) landing, which is most frequently witnessed during slower paced locomotor tasks such as walking and jogging (Cortes et al., 2007). The second method is the toe-heel (forefoot) landing strategy (Cortes et al., 2007), which is commonly performed whilst individuals are landing from a jump movement as seen in basketball, volleyball and many other sporting activities (Cortes et al., 2007). The forefoot landing can be per-

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formed in two different styles; one where the heel does not come into contact with the ground and the forefoot takes the entirety of the contact. This landing style has been identified by Puddle and Maulder (2013), as a landing predominantly recruited by traceurs during drop tasks and is referred to as a 'precision landing'. The second method of forefoot landing is where the heel does come into contact with the ground for the purpose of medial/lateral stability, shock absorption and/or counterbalance (Kovacs et al., 1999). In comparison to rear-foot landings, forefoot landings provide the individual the opportunity to demonstrate a greater level of hip, knee and ankle flexion, which in turn allows the GRFs to be dispersed throughout the musculoskeletal system over a longer period of time; therefore decreasing the risk of injury (Bressel and Cronin, 2005; Cortes et al., 2007; Gross and Nelson, 1988).

Past research has investigated both of these landing strategies, delving into both the kinetic and kinematic variables associated with each method. Literature has shown that differing degrees of flexion at the hip, knee and ankle during landing, can influence the GRFs and dispersion of these forces through the musculoskeletal system; therefore influencing the likelihood of corresponding injuries (Blackburn and Padua, 2009; Horita et al., 2002; Wikstrom et al., 2006). Kinetic variables such as peak vertical GRF (Bisseling et al., 2007; Blackburn and Padua, 2009), time to peak vertical GRF (Caulfield and Garrett, 2004), loading rates (Bauer et al., 2001; Ricard and Veatch, 1990) and also muscular EMG activity (Horita et al., 2002; Tillman et al., 2004), have also been investigated in an attempt to quantify their relationship with the aforementioned kinematic variables associated with landing. As stipulated by a large range of articles, the testing population can also play a large role in generating consistently replicable data sets; as factors such as gender (Salci et al., 2004), age (Swartz et al., 2005), training status (McNair and Prapavessis, 1999) and sporting background (Bressel and Cronin, 2005), can all influence the kinetic variables associated with different landing strategies.

Although the combination of these mechanical variables provides researchers insight into the inner workings of different landing techniques, there is one variable that is rarely discussed, despite its frequent anecdotal utilisation when teaching landing strategies to sportsman and children, by coaches and regional Parkour leaders. It us suggested that the sound produced during a landing has a relationship with leg stiffness, landing strategy (forefoot vs rear-foot) and several kinetic variables including peak vertical GRF (Mcnair et al., 2000; Prapavessis and McNair, 1999). Research has identified that when participants focused on landing more quietly, the trials were often associated with greater range of movement through the lower limb joints, lower peak vertical GRFs and therefore lower risk of injury (Prapavessis and McNair, 1999).

With the continuing growth of Parkour, methods are being developed to establish the safest and most effective strategies to achieve their movement objectives. With landing being a pertinent part of this practise, traceurs have devised their own habitual landing strategies. These particular landing strategies have been practised by traceurs, as they believe them to be the most effective style for completing the tasks involved with their activity. Based on this statement, it can be assumed that due to this learning effect, their habitual landing strategies would differ from the recreationally trained individual. A study by Puddle and Maulder (2013), identified two styles of Parkour landings that have been utilised in Parkour, the roll and the precision landing. Results of this study suggested that the precision landing may be a safer alternative than the traditional forefoot to heel landing that is utilised in many recreational based activities such as volleyball and basketball. This precision landing is categorised by a forefoot touchdown (no heel contact), bending of the knees to absorb impact, no varus or valgus knee movements and the use of the arms to counterbalance the movement. For a visual representation of these movements, refer to figures published in Puddle and Maulder (2013). The study by Puddle and Maulder (2013), showed a significantly lower level of peak vertical GRFs, as well as a longer time to peak force during the precision landing, in comparison to the traditional forefoot landing data. Although this technique may be safer, drop jump height is an important factor to consider when comparing different jumping styles and techniques. Research has identified that as height of drop jump increases, kinetic and kinematic variables such as degrees of lower limb flexion, peak GRFs, time to peak GRF and velocity of limbs are all effected during the landing phase, despite the style of technique being utilised (Yeow et al., 2009; Zhang et al., 2008). Whilst Puddle and Maulder (2013), made speculative comparisons to traditional landings typically utilised by a recreationally trained population from the temporal and kinetic measures taken from Parkour precision and Parkour roll landing techniques at an absolute height (0.75m), what is needed is an understanding of whether or not recreationally trained athletes do in fact land differently to traceurs from varying heights. It is evident that there is limited empirical evidence available in regards to biomechanical parameters associated with movement patterns utilised during Parkour practises; therefore more research is required to understand the kinetic and kinematic variables associated with different landing strategies from varying heights.

The purpose of this study was to compare the habitual landing strategies of Parkour practitioners (traceurs) and recreationally trained individuals from differing drop heights. Furthermore, landing sound and mechanical parameters were assessed to gauge the level of landing safety, with these measures compared between the two groups.

It was hypothesised that the habitual landing strategy of recreationally trained individuals involved a forefoot to heel landing technique, whereas traceurs utilised a "precision" landing strategy that is predominantly forefoot only. It was also hypothesised that compared to the recreationally trained individuals, traceurs would land more quietly with less vertical ground reaction force and an overall lesser loading rate.

Methods

Participants

New Zealand based traceurs (n = 10) and recreationally trained individuals (n = 10) volunteered for this study. Traceurs were recruited through the NZ Parkour association and recreationally trained individuals were recruited from sporting / gym communities. The recreationally trained participants typically participated in sporting pursuits that required various amounts of jump landings. All participants were required to be within the ages of 16 and 30 years old and had to be free from lower limb injuries within the two months prior to testing. A prerequisite of at least 1 year Parkour training experience was required for the traceurs, whereas the recreationally trained individuals were required to participate in a minimum of 30mins per day of moderate-high intensity exercise, at least four days per week, for a minimum of 12 weeks prior to testing. A comparison of group characteristics can be observed in Table 1. Participants were provided with an information sheet outlining the details of their involvement prior to participation in the current study. Those who agreed with the procedures and protocols then signed a written consent form before any testing was undertaken. Ethical approval was sought and approved for all procedures from the Institute's Ethics Committee.

Table 1. Characteristics for traceurs and recreationally trained participants. Data are means (±SD).

	Traceurs	Recreational	ES
Age (yrs)	21.7 (3.6)	24.3 (3.4)	.73
Height (m)	1.78 (.07)	1.77 (.06)	.03
Mass (kg)	75.8 (7.0)	80.1 (6.1)	.62
Training (yrs)	4.9 (2.6)	8.6 (3.0) *	1.19

* = significant difference ($p < 0.05$), ES = effect size.

Experimental procedures

All participants attended a single testing session which included both familiarisation and data collection. For both procedures they were advised to wear their preferred training shoe and training attire. Before recording any trials, participants performed a warm-up involving five minutes of static cycling at a rate of 80rpm, followed by self-directed dynamic stretching. Post warm-up, their dominant leg, or leading leg as it will be referred to hereafter, was determined during the familiarisation period and was then utilised during the testing period for all trials to ensure consistency. Both traceurs and recreationally trained individuals exhibited a 60% (6/10) preference in favour of the right leg as the leading leg. Participants then performed three to five familiarisation trials from each of the two drop landing heights (25% and 50% of standing body height), for a total of six to ten trials in all. One minute rest periods were provided between familiarisation trials. In order to determine habitual landing technique, the only technical instruction given was "step off and land". In order for participants to feel comfortable with the step off protocol, they were told to step from the platform without crouching down or jumping up (Decker et al., 2003). Once familiarisation had occurred and the researcher was satisfied, testing was able to begin. This involved participants being randomly assigned a block randomised trial sequence for the drop landing heights. This was to reduce the effects of test order bias.

Participants begin the testing protocol by ascending onto a platform via a set of steps, before standing at the front face of the platform with their toes at the edge. At a cue from the researcher ("step off and land"), participants stepped out with their leading leg (without jumping up or crouching down) and performed their habitual landing technique. Participants were observed as they stepped out from the platform to rule trials as acceptable or unacceptable based on their ability to conform to the protocol. All landings for a drop landing height were performed consecutively, before changing to the trials of the second drop landing height. Between performances of a successful landing trial (landing is on the centre of the force plate and the correct technique is used), three minute rest periods were provided with three minutes of rest also between changes in drop landing heights.

Data collection

Participants performed all their trials from an adjustable platform (SDJA1500 Manual Stacker). The platform was situated 0.2m away from the edge of a 0.9m x 0.6m embedded force plate (Kistler, Switzerland), with a marked target (30cm by 30cm) centred 0.6m from the platform edge to ensure adequate contact when stepping from the platform. The force plate was used to record all kinetic variables of interest and sampled at a rate of 1000Hz. BioWare 4.1 software was used to collect all the relevant kinetic data. A professional sound level meter (Digitech QM1592) capturing at a rate of 2Hz was utilised to measure the sound of each landing. The microphone was placed 0.2m from the force plate edge (0.6m from landing target) and was situated 0.15m high, angled down at the target. A high speed camera (Casio exilim, EX-F1) was utilised to capture the landing technique using a frame rate of 300 Hz. It was placed perpendicular to the landing target at a 4.5m distance and stood 0.6m high. From this Hi-speed footage, the habitual landing strategy was determined qualitatively.

Data analysis

Data extrapolation was achieved with the use of BioWare 4.1 software. Vertical ground reaction forces were low pass filtered using a fourth-order Butterworth filter, with a 50 Hz cut-off frequency (Johnson and Buckley, 2001). Data was then exported to Ms Excel (2010), where the variables of interest were examined. The variables of interest derived from the force plate, sound device and high speed camera were as follows:

Maximal vertical ground reaction force (BW) – This is the highest peak of force recorded during each landing, via the force plate (Puddle and Maulder, 2013). Loading rate (BW/s) – This is the speed at which forces impacted the body. It was calculated by dividing the maximal vertical force by the time to the maximal vertical force (Bauer et al., 2001; Crossley et al., 1999).

Time to maximal vertical ground reaction force (ms) – Defined as the time taken to reach the maximal vertical force from initial contact. It is calculated by subtracting the time at maximal vertical force by the time at initial contact (where the vertical force exceeded 50N (Cronin et al., 2008)).

Maximal sound (dB) – This is the highest peak of sound recorded during landing, via the data collected by the sound level meter.

Foot strike technique – This was a qualitative analysis performed from the high speed camera footage taken of the landings, where touchdowns were ranked into one of three categories. Forefoot only landing (1/3 of foot), forefoot to mid-foot landing ((no heel) 2/3 of foot) and forefoot to heel landing ((heel contact) 3/3 of foot) (Bressel and Cronin, 2005; Munro et al., 1987; Puddle and Maulder, 2013).

Within session reliability for the aforementioned variables expressed as typical error (coefficient of variation %) outcomes can be observed in Table 2. The trend in results suggested maximal sound and maximal vertical ground reaction force revealed reasonable levels of reliability for both groups and heights, whereas time to maximal vertical ground reaction force and loading rates tended to have a lower reliability.

Table 2. Typical error as a coefficient of variation % for sound and temporal kinetic measures during landings performed from two heights relative to standing height (25% and 50%) for Traceurs and recreationally trained participants.

	Traceurs		Recreational	
	25%	50%	25%	50%
Maximal sound (dB)	6.1	8.2	8.8	11.7
mVF (BW)	8.5	7.4	12.1	13
Time to mVF (ms)	21.2	25.3	18.0	6.6
Loading rate (BW/s)	22.4	27.4	25.5	17.9

dB = decibels, mVF = maximal vertical force, BW = bodyweight, ms = milliseconds.

Statistical procedures

Comparisons were made between sound and kinetic parameters exhibited by the traceurs and recreationally trained individuals using the methods of Hopkins (2006). These analyses allowed for p values ($p < 0.05$ was deemed to be statistically significant), Cohen effect sizes, 90% confidence intervals, and qualitative inferences to be presented, which is currently considered the most meaningful practice for statistical use in sports medicine and the exercise sciences (Hopkins et al., 2009). Specifically, differences between traceurs and recreationally trained individuals are expressed as a percentage via analysis of log-transformed values using natural logarithms. To make inferences about the true values of the percentage differences and effect sizes between traceurs and recreationally trained individuals, the uncertainty in the percentage differences and effect sizes are expressed as 90% confidence intervals and as likelihoods that the true value of the difference is substantial (Batterham and Hopkins, 2006). A difference was deemed unclear if its confidence interval of the effect statistic overlaps substantially positive and negative values and the threshold for the smallest worthwhile effect, otherwise, when a result is above the threshold for the smallest worthwhile effect the results are given as: 0 – 0.2 trivial; 0.2 – 0.6 small; 0.6 – 1.2 moderate; 1.2 – 2.0 large; 2.0 – 4.0 very large. An effect size of 0.2 was chosen to be the smallest worthwhile difference in the means in standardized (Cohen) units as it gives chances that the true effect would at least be small (Cohen, 1990).

Results

Statistically significant ($p < 0.05$) differences were found in mean values for all variables of interest, in both the 25% and 50% landing heights, with the exclusion of the maximal sound measurement at the 25% height (see Table 3). Percentage differences and effect sizes are displayed in Table 4, which have identified a range of effect sizes from ‘trivial’ to ‘very large’ for each of the variables outlined in the methods section.

Table 3. Mean (SD) variable outcomes of sound and temporal kinetic measures during precision landings performed from two heights relative to standing height (25% and 50%) for traceurs and recreationally trained participants.

	Traceurs		Recreational	
	25%	50%	25%	50%
Maximal sound (dB)	64.2 (3.3)	64.1 (2.7) †	66.6 (4.1)	70.4 (7.9)
mVF (BW)	2.5 (0.2)*	3.6 (0.4) †	4.4 (1.8)	7.4 (2.9)
Time to mVF (ms)	91 (16)*	56 (14) †	57 (22)	35 (10)
Loading rate (BW/s)	29.9 (7.0)*	83.3 (62.3) †	99.2 (69.6)	247.8 (142.3)

dB = decibels, mVF = maximal vertical force, BW = bodyweight, ms = milliseconds, * = significant difference (p<.05) between groups for 25% height, † = significant difference (p< .05) between groups for 50% height.

Table 4. Differences between traceur and recreationally trained participant landings (traceur – recreational) at both drop landing heights (25% and 50%), including qualitative inferences about the effects of those differences.

	Height	p value	Diff. in means as Percentage (%)	Diff. in means as % 90% confidence levels lower	upper	Cohen ES	Qualitative inference ranges of ES
Maximal sound (dB)	25%	.1621	-3.6	-7.6	.7	-.63	large – trivial (-ive)
	50%	.0300*	-8.6	-14.3	-2.5	-1.04	large – small (-ive)
mVF (BW)	25%	.0013*	-39.9	-51.0	-26.3	-1.88	v large – moder. (-ive)
	50%	.0002*	-49.0	-58.8	-36.9	-2.38	v large – large (-ive)
Time to mVF (ms)	25%	.0015*	68.6	34.2	111.7	1.72	moder. – v large (+ive)
	50%	.0067*	65.9	24.7	120.6	1.32	small – v large (+ive)
Loading rate (BW/s)	25%	.0002*	-65.1	-75.5	-50.2	-2.22	v large – large (-ive)
	50%	.0002*	-66.3	-77.6	-49.5	-2.00	v large – large (-ive)

dB = decibels, mVF = maximal vertical force, BW = bodyweight, ms = milliseconds, Diff. = difference, ES = effect size, * = significant difference (p< .05), v large = very large, moder. = moderate, -ive = negative, +ive = positive.

Data surrounding mVF has revealed traceurs exhibited a significantly ($p = 0.0013$, $p = 0.0002$) lower peak mVF(BW) (-39.9% and -49%) in comparison to the recreationally trained participants, which corresponds with 'large' and 'very large' effect sizes for both the 25% and 50% drop heights, respectively (see Table 4).

The maximal sound produced by the traceur group was significantly ($p = 0.03$) lower than the recreationally trained participants during the 50% drop height (64.1dB and 70.4dB, respectively). At the 25% height there was no significant difference between the groups ($p = 0.1621$), however an effect size of -0.63 was observed which demonstrates a 'moderate' difference (see Table 4).

The traceur group also demonstrated a significantly longer time to mVF at both the 25% and 50% heights ($p = 0.0015$, $p = 0.0067$, respectively) in comparison to the recreationally trained group. Traceurs took 68.6% longer to reach mVF at the 25% height and 65.9% longer at the 50% height, indicating a 'large' and 'very large' effect size at respective heights (see Table 4).

Loading rates between the two groups were also significantly different at the 25% height ($p = 0.0002$), with the mean values of 29.9BW/s and 99.2BW/s being identified between the traceur and recreationally trained participants, respectively (see Table 3). Similarly, the traceurs exhibited a mean value (83.3BW/s) significantly lower ($p = 0.0002$) than the recreationally trained group (247.8BW/s) at the 50% height, indicating a 'very large' effect size at both drop heights.

Foot strike analysis has indicated that during the 25% height landings, 100% of traceurs touchdowns were performed on the forefoot, or forefoot-midfoot only. The recreationally trained individuals demonstrated contrasting results, with data revealing that 86.6% of touchdowns incorporated the heel contacting the ground. This trend continued in the 50% heights, with traceurs performing 26 from 30 landings (86.6%) using forefoot, or forefoot-midfoot only during their landing phase. Recreationally trained participants produced results proving 96.6%, or 29 from 30 landings incorporated heel contact during touchdown. The traceur 'precision' landing was observed in a total of 55 of the 59 trials during this study (93.2%) from the Parkour group, with only 5 trials (8.3%) of the recreationally trained group showing similar technical aspects (see Table 5).

Discussion

The purpose of this study was to compare landing sound and mechanical parameters between the habitual landings strategies of traceurs and recreationally trained individuals from differing drop heights, in an attempt to gauge the safety of the landing techniques utilised by the two groups. Maximal vertical ground reaction force, time to maximal vertical ground reaction force and loading rates have each been identified as having a relationship with injury rates in landing based activities (Zhang et al., 2008; Ricard and Veatch, 1990; Woodard et al, 1999); therefore these variables were selected for observation and will be discussed accordingly. It was hypothesised that the habitual landing strategy of recreationally trained individuals would involve a forefoot to heel landing technique, whereas traceurs would utilise a "precision" landing strategy that is predominantly forefoot only. It was also hypothesised that compared to the recreationally trained individuals, traceurs would land more quietly with less vertical ground reaction force and an overall lesser loading rate. Findings of this study support this hypothesis, with significant differences found between peak vertical GRF, time to maximal vertical GRF and loading rates between the two groups at both 25% and 50% heights. Maximal sound was significantly different at the 50% drop height; however this significance was not seen at the 25% height. It was also identified that traceurs incorporated a 'precision' style landing during 93.2% of their total trials, while the recreationally trained participants used predominantly (91.7%) forefoot-heel landing strategies.

Table 5. Number of landings performed using different foot strike techniques by traceur and recreationally trained participants at both drop heights (25% and 50%).

	Height	Number of traceur landings	Number of recreational landings
Forefoot only	25%	14	0
	50%	9	0
Forefoot to mid-foot	25%	15	4
	50%	17	1
Forefoot and heel	25%	0	26
	50%	4	29

As stated by McClay et al., (1994), GRF is a measure of the magnitude of stress placed upon an individual during a ground contact. The higher these GRFs, the larger the stress on the musculoskeletal system and therefore the greater the risk of injury to the individual (Bressel and Cronin, 2005; Irmischer et al., 2004). The results of this study showed that the Parkour precision landing strategy demonstrated significantly less vertical GRFs (2.5BW, 3.6BW) in comparison to the recreationally trained individuals (4.4BW, 7.4BW), during the 25% and 50% drop landings, respectively. This data suggests that due to the lesser peak GRFs on impact, the Parkour precision landing was indeed a safer method of touchdown than the habitual landing strategies of the recreationally trained participants.

Past research has investigated many variables that are associated with changes in vertical GRFs, such as different landing styles, participant population types, varying sporting codes and variable drop heights. Although these factors have been shown to influence the level of GRFs recorded, the results of this study still fall within similar ranges to what has previously been reported. For example a study by Prapavessis and McNair (1999), identified that habitual landing techniques of 91 high school students had a mean vertical GRF of 4.53BW, when landing from a 0.3m height. This study provides similar vertical GRF readings to those witnessed in the current study, especially in terms of the recreationally trained participants at the 25% drop height (~0.44m), which was similar to the height used by Prapavessis and McNair (1999).

A study by Zhang et al., (2008) reported vertical GRFs of ~7BW in a group of 10 physically active men, whilst dropping from a 0.75m height using their own habitual landing strategies. Similarly, McNitt-Gray et al., (1993), conveyed that during drop landings from a height of 0.72m, nine female gymnasts produced vertical GRFs of ~6BW when using their own preferred style of landing. The habitual landings of the recreationally trained participants in the current study fall well within the constraints of the data reported by these previous studies, therefore verifying their validity and consistency; however, the Parkour precision landing has been reported to produce less than half of the vertical GRFs stated by McNitt-Gray et al., (1993), Prapavessis and McNair (1999) and Zhang et al., (2008), even when dropping from heights 0.1 - 0.15m higher. Previous investigations into Parkour style landings by Puddle and Maulder (2013), established that during drop landings from a 0.75m height, the precision style landing demonstrated vertical GRFs of ~3.2BW, which is similar to those seen in this current study. There are several explanations that may provide insight into why the Parkour precision landing generates such little vertical GRF. The first possible justification encompasses the postural position of the torso during touchdown. According to Blackburn and Padua (2009), flexion of the trunk during landing increases the level of hip and knee flexion and therefore decreases the magnitude of GRFs during the movement. This statement is backed by the findings of Horita et al., (2002) and Wikstrom et al., (2006), who state that vertical GRFs can be lessened with increased flexion at the hip and knee, as this allows the forces to dissipate throughout the surrounding joints and musculature. Although these kinematic parameters were not measured quantitatively within the current study, based on the qualitative observations (as per the video footage) the traceur landings predominantly incorporated a larger degree of flexion at the hips during touchdown, in comparison to the recreationally trained individuals, which intuitively would lead to minimised GRFs during the movement. However, a more thorough kinematic/kinetic analysis is recommended to validate such assumptions.

The second possible explanation for the lower GRFs during the Parkour precision landing is the impact of the heel during touchdown. When the heel comes into contact with the ground during landing, it is typically due to the individuals technique, or lack of ability to control the eccentric forces involved with decelerating the landing velocity (Gross and Nelson, 1988). The more an individual can slow the movement eccentrically, the larger the dissipation of force throughout the corresponding joints and musculature, which therefore lessens the GRFs measured during the movement (Cortes et al., 2007; Gross and Nelson, 1988). Foot strike data obtained within this current study identified that during the majority of landings, traceurs landed predominantly (93.2%) on their forefoot alone, or their forefoot and mid-foot combined (55 from 59 landings). This meant they were strong enough and had adequate technique to slow the landing to a point they could control the movement. On the other hand, the recreationally trained individuals landed on their forefoot, before making contact with their heel in 55 out of 60 landings (91.6%). This suggests they could not slow the movement or dissipate the force as effectively as the traceurs and therefore generated the higher GRFs.

The magnitudes of postural flexion (hip, knee and ankle), as well as the foot strike technique employed during landing may also begin to explain the differences identified between the traceurs and the recreationally trained individuals time to mVF. Results of this study revealed that traceur time to mVF was significantly longer (68.6% and 65.9%) at the 25% and 50% heights, than the recreational group. Mean values of 91ms and 56ms were identified for the traceur group with corresponding values of 57ms and 35ms for the recreationally trained group, at jump heights of 25% and 50% body height, respectively. Previous research undertaken by Puddle and Maulder (2013), identified similar mean times to mVF when comparing Parkour precision landings (80ms), to traditional landing styles (forefoot to heel) (40ms), from a height of 0.75m. Times witnessed in both the current study and the one performed by Puddle and Maulder (2013), have exhibited values below 50ms. According to a study by Ricard and Veatch (1990), the neuromuscular system requires a minimum of 50ms to react to an applied stimulus, such as a landing touchdown. Any impact prior to this 50ms threshold is likely relying on muscular pre-activation to disperse the force and provide shock attenuation during the movement. Based on this statement, the recreationally trained participants landing from the 50% height, do not have enough time for their neuromuscular system to activate prior to the mVF, as time to mVF is a mare 35ms. This lack of neuromuscular activation correlates to a higher risk of injury in the corresponding joints and musculature involved with the movement, especially at the instance of mVF occurring (Bauer et al., 2001; Butler et al., 2003; Ricard and Veatch, 1990; Yeow et al., 2009).

Although the variable was not measured within the current study, it is plausible that traceurs have a larger degree of muscular pre-activation prior to touchdown, which provides enough elastic potential within the muscles to slow the movement longer than the 50ms threshold, as stipulated by Ricard and Veatch (1990). This permits the neuromuscular system to be stimulated effectively and therefore allows the individual to activate the relevant musculature, providing flexion of the hip, knee and ankle, which in turn maintains a forefoot only landing strategy (no heel), decelerates the bodies mass, lowers the peak GRFs and also lengthens the time to mVF (Bauer et al., 2001; Butler et al., 2003; Gross and Nelson, 1988; Yeow et al., 2009). This process of lengthening the time to mVF has been stated to decrease the likelihood of skeletal injuries, therefore proving traceurs precision style landing is indeed a safer landing alternative than the habitual landing strategies employed by the recreationally trained participants (Bisseling et al., 2007; Bressel and Cronin, 2005). A recommendation for future studies is to investigate the effects of augmented feedback using cues derived from the traceur precision landing on recreationally trained individuals. This would help to identify if it is simply knowledge of landing technique, experience, practise, or a particular physical requirement that is needed to perform the landing strategy effectively. If the recreational groups can produce safer landings by simply being taught this technique, it provides a great opportunity for other sports to follow in the footsteps of traceurs and incorporate this technique into training sessions.

The loading rates associated with landings have been stated to be one of the best indicators of soft and hard tissue injuries of the lower extremities (Woodard et al., 1999). The loading rate refers to the amount of force an individual encounters in relation to the speed at which peak force is attained (force ÷ time to peak force). The higher the loading rate of a landing movement, the greater the stress that is placed upon the musculoskeletal system. The current study showed loading rates of 99 ± 69.6 BW/s and 248 ± 142.3 BW/s at the 25% and 50% heights, for the recreationally trained participants. These values are similar to those reported by Decker et al., (2003), who measured loading rates of male recreational athletes from a 0.60m habitual drop landing, that produced mean values of 96.18BW/s. This study also tested females using the same protocol, who produced significantly greater loading rates of 162.11 BW/s. Contrastingly, a study by Bauer et al., (2001), identified loading rates of 472 ± 168 BW/s in prepubescent children, whilst dropping from a 0.61m height using their own habitual landing strategies. This data suggests the loading rates can vary largely, with additional research suggesting this can be due to gender (Decker et al., 2003; Fagenbaum and Darling, 2003; Salci et al., 2004), age (McKay et al., 2005; Swartz et al., 2005), landing strategy (Blackburn and Padua, 2009; Bressel and Cronin, 2005; Cortes et al., 2007) and/or drop height (McNitt-Gray et al., 1993; Yeow et al., 2009). These factors begin to explain why the Parkour landings produced loading rate values much lower than those witnessed in the majority of previous literature. During the 25% and 50% drop jump heights, traceurs exhibited loading rates of 29.9 ± 7 BW/s and 83.3 ± 62.3 BW/s, which are significantly lower than the recreationally trained individuals (99 ± 69.6 BW/s and 248 ± 142.3 BW/s). Puddle and Maulder (2013), also obtained similar values for Parkour precision landings from a 0.75m drop height (83.3 ± 80.1 BW/s). In the current study and the one performed by Puddle and Maulder (2013), variables such as gender, age and drop height were kept consistent between the two population samples, which leaves landing strategy as a possible reasoning for the variances in values. As stated previously, the ability to lower peak GRFs and lengthen the time to mVF, are critical in minimising the corresponding loading rate (Bauer et al., 2001; Blackburn and Padua, 2009; Cortes et al., 2007). This has been explained through the use of larger degrees of hip, knee and ankle flexion, as well as stronger eccentric contractions of the relevant musculature, which in turn allows a forefoot landing strategy. By doing so, the traceurs are ultimately lowering the probability of musculoskeletal injuries caused by high loading rates. Currently, there is only this present study and the findings of Puddle and Maulder (2013), that have investigated the kinetics of the Parkour landing strategies. In both instances, the data has revealed that in acute scenarios the technique proves to be safer and more efficient than the standard forefoot to heel technique. However, future research is required to identify if repetitive landings using this technique is as effective as a single landing. This is vital for traceurs, who often perform more than one landing in sequence. Due to factors such as muscular fatigue from eccentric loading, smaller surface area to balance (forefoot only) and a vast variety of landing surfaces that are associated with the activity, it is possible that these landings may prove less effective in a real-world scenario. Future studies also need to investigate the longitudinal effects of the Parkour precision landing technique. With larger focus on dissipating the force throughout the lower limb musculature, it is possible that other faults such as shin pains, patella tendonitis and achilles injuries may occur, especially if the participant is not accustomed to this style of loading or landing style. This may also connect with studies investigating the effects of training status and its relation to the effectiveness of precision landings in differing population groups.

Previously, sound has been used as a measure of landing efficiency and safety in sporting and teaching environments. Although there is very little scientific research investigating this parameter, it is suggested that it may in fact have some credibility. Results of this study show that the recreationally trained individuals produced significantly louder (70.4 ± 7.9 dB) landings from the 50% height, in comparison to the traceurs (64.1 ± 2.7). This trend was also observed at the 25% drop height with a moderate effect size shown, or 3.6% quieter landing observed in the traceurs, in contrast to the recreationally trained group. It can be speculated that this increase in sound during landing can be attributed to multiple kinematic and kinetic factors involved with the recreationally trained groups landing technique. Firstly, it has been established that the recreational group were less effective than the traceurs at decelerating the landing velocity. This is likely due to increased postural stiffness during landing, lack of eccentric strength and/or variations in technique; which in turn lead to increased GRFs and a faster time to mVF. This suggests they are landing at a faster speed than the traceurs, with larger forces and with a shorter time to dissipate these forces. The combination of these parameters have been suggested to induce a larger maximal sound, or decibel reading at touchdown based on the findings of Prapavessis and McNair (1999). This is also exaggerated by the fact traceurs landed predominantly forefoot and forefoot-midfoot (93.2%), whereas the majority of recreational group landings occurred with heel contact during touchdown (91.6%). This increased the total surface area of contact upon touchdown, which may also increase the likelihood of a louder landing. In terms of validating the ability of sound to be used as a measure of landing effectiveness and safety, all contributing variables must be taken into account. Increases in the likelihood of injury have been stated to be related to higher peak GRFs, shorter time to peak mVF and also higher loading rates (Bisseling et al., 2007; Bressel and Cronin, 2005; Butler et al., 2003; Dufek and Bates, 1990; Irmischer et al., 2004). Each of these factors have been proven to be safer in the habitual landing style of the traceurs, based on the values collected in this study. This group has also been identified as achieving a significantly quieter landing touchdown in comparison to the recreationally trained group. This suggests sound can in fact be a valid predictor of landing safety and effectiveness when being performed at a height of 50% body height, whilst using a precision style landing. Future research should be directed at explaining the reasons for the dissimilarities in significance between the two drop heights, as this data suggests that there may be a minimum drop height (above 25% body height), where sound is then deemed a feasible predictor of landing efficiency. It is suggested that future research test for maximal sound from a variety of heights between 25% and 50% of body height, to establish at what point the sound becomes significant.

One limitation to this study is the lab based environment that the testing occurred in. Parkour is an activity that is often performed in urban areas with many different variables influencing the speed, distance and technique involved with traceur jumping and landing activities. By bringing these individuals into a lab based environment where all of these variables are controlled, it may have influenced some of the technical aspects of their performance. By standardising the step off method and landing target, it may have altered the habitual landing technique that the traceurs would have used out in the field. Another limitation in regards to this study is the style of footwear the individuals used during testing. All participants were instructed to wear their own choice of footwear, after being told they would be performing physical exercise and landings from height. It was evident that there was a variety of shoe types, ranging from light weight climbing style shoes, to heavy skater sneakers. The variances within the footwear may well have influenced the forces and sound associated with those landings. A final limitation of this study is based on the fact each of the landing trials was planned and executed with full awareness from the participant. When investigating landing safety or collaborating injury research, it is probable that this data comes from sporting based activities. Movements within this environment are often not planned in advance and happen at short notice; however in this testing environment each of the landings was pre-empted and controlled by the participant. In terms of judging safety, it can be stated that precision style landings are the safer strategy when compared to the recreationally trained individuals habitual landing technique in a lab-based environment; however it is unclear if this is the case in a sporting environment.

Conclusion

The results of this study suggest that the habitual landing strategies of traceurs (precision landings) are a safer technique than the habitual landings observed in recreationally trained individuals. This is based on the findings revealing traceurs exhibited significantly less vertical GRFs, longer times to mVF, and lesser loading rates, which have all been associated with a lesser likelihood of injury. Future research should investigate the use of technical feedback to recreationally trained individuals during drop landings, in an attempt to optimise the safer kinematic and kinetic variables associated with the precision landing of the traceurs. Results also suggest that maximal sound is also a relevant indicator of landing safety, as the safer landing strategy also had a significantly lower maximal sound at the 50% height. Because these results were not conclusive at the 25% height, more research is required to identify at which height sound becomes a determining factor, especially within general sporting populations. The findings of the current study provide insight for traceurs in and around the effectiveness of their current landing strategies. The alterations of body mechanics in comparison to the habitual style witnessed in recreationally trained individuals suggests there may be some benefits in adopting the precision style landing in other landing sports. Further research is still required to understand the feasibility of performing precision landings repetitively and longitudinally; however in the short term, these safer landings indicate a lower injury risk and therefore a longer playing career.

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Key points

- Habitual traceur landings were observed to be safer landing techniques in comparison to those utilised by recreationally trained individuals, due to the lower maximal vertical forces, slower times to maximal vertical force, lesser loading rates and lower maximal sound.
- Traceurs predominantly landed with the forefoot only, whereas recreationally trained individuals habitually utilised a forefoot to heel landing strategy.
- The habitual landing techniques performed by traceurs may be beneficial for other landing sports to incorporate into training to reduce injury.

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