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School of Sports Science and Physical Activity

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Comparison of unilateral lower limb dynamic stability between parkour athletes and physically active people

BY

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Abstract:

Parkour is a new sport that emerged from Paris, France in early 1990s, with probably only sport- specific movements such as landing or take off techniques or neuromuscular techniques characteristic for Parkour researched. It appears that there is lack of research in dynamic balance in Parkour, with no data available at scores and how they compare with people with different sport background. The aim of this study was to assess Parkour athlete's unilateral lower limb balance using SEBT and HOP Test and compare them with non-Parkour, but physically active people and provide results that could possibly be used in further research in this area, with hypothesis that Parkour athletes would score higher in both tests. 5 Parkour and 5 non-Parkour healthy male participants took part in the study. All 8 SEBT reaches and full battery of HOP Test scores from each leg were assessed in within-groups comparison. Parkour group had significantly higher Single (right leg: $P < 0.001$, left leg: $P = 0.001$), Triple (right: $P = 0.002$, left: $P = 0.003$) and Crossover (right: $P = 0.007$, left: $P = 0.003$) HOP Test scores. No significant differences were observed in SEBT scores apart from Right leg Posterior ($P = 0.028$) and Posteromedial ($P = 0.036$) reach.

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Introduction

Parkour is a relatively new sport that has been developed in late 1980- early 1990s in France by an individual named David Belle. “Parkour” as official name of this discipline started to be used in late 1990s, where previous name for the sport was “Art du Deplacement”- which translates to “Art of Moving”. Parkour has become popular due to videos posted on the internet by parkour practitioners known as “Traceurs” or “Freerunners”, with the latter being more common. During 2000s, more and more Freerunners started to appear on broadcasted shows, performances and Hollywood productions even managing to get parkour dedicated tv shows on MTV, and parkour dedicated films (Yamakashi, District 13) attracting international brands such as RedBull. In 2007, World Parkour and Freerunning Federation has been created with intentions to bring Parkour with its philosophies to the broader audience *(Kidder, 2012).* In 2016, United Kingdom has become the first country in the world to officially recognize Parkour as a sport. As of 2022, Parkour is a worldwide known discipline where athletes are considered highly skilled professionals employed by international brands, with classes, performances, competitions, leagues and even gyms dedicated purely to parkour being ran around the globe *(Stapleton, Terrio., 2010*).

Parkour can be described as practice of traversing obstacles in natural or urban environment by using jumping, running, climbing, vaulting, rolling, flipping, or swinging to travel from one point to another in the quickest way possible. These activities are characterised by single and double legged jumps often covered by huge distances within a span of one or many jumps. They usually involve big impact landings, direction changes with every move and highly technical flips, all of which require excellent motor control and coordination. Apart from physical demands, Parkour also requires huge tolerance to mental stress, confidence and trust in individuals own capabilities, with psychological side of the sport being as important as physical (*Kidder, 2013*). These traits combined with environment that this sport is being practised in creates unique discipline with possibly one of the highest physical demands from a practitioner. (*Gosprêtre, Leppers., 2016*)

Parkour, being a sport that predominantly focuses on lower limbs, requires high levels of strength and coordination. It also demands that a practitioner that wishes to undertake this kind of activity to have excellent dynamic balance in both of their legs to ensure success in completing every jump and avoid injuries during training session. Many aspects of Parkour are still not researched, with single leg balances being one of them, which questions, whether Freerunners have different levels of stability compared to other sports or activities. This creates a gap in literature about Parkour practitioners as athletes and knowledge about this discipline in general. Single leg activities are one of the most common ones used in the sport alongside double leg activities in every aspect of Parkour: take off, landing, direction change, flipping, transitioning, vaulting. Using single leg allows to carry more speed throughout the movement, which can be converted into further distance covered during a jump or a vault. Due to the distances covered, impact needed to absorb and other important characteristics of the sport, single leg stability during movement is a crucial factor in Parkour performance, creating a necessity for research about lower limb dynamic stability in Parkour. This study aims to assess Freerunners in unilateral dynamic stability tests, measure their scores, and compare them with physically active population.

Literature Review

Search Strategy

Research review for this study aimed to discover the researched area and collect relevant information that could help to rationalize research. Google Scholar, and EBSCO DISCOVER services available at the University of Bedfordshire were used for literature search. Review has started from reviewing available studies covering Parkour, with key words being Parkour, Parkour history. After initial review and analysis of topics covered by research in Parkour, search was narrowed to research related directly to the study, with keywords being Parkour stability, Parkour dynamic stability, Parkour HOP test, Parkour SEBT, Parkour single leg jump, Parkour biomechanics, Parkour jump biomechanics, Parkour landing, Parkour single leg landing, Parkour squat, Parkour squat performance. After completing Parkour related search, additional research related to human physiology, biomechanics and training methods surrounding the research area was conducted, with intention to provide more accurate information and background about movement that was going to be assessed with total number of studies being 48.

Literature Review

Compared to other sports, Parkour has not been thoroughly studied, with possibly many aspects of the sport not researched at all. Most of the research about Parkour tends to focus on Parkour- specific movements or Traceurs traits analysis such as performance characteristics of a Traceur (*Gosprêtre, Leppers., 2016*), landings (*Maldonado et al., 2018;*

Maldonado et al., 2015), specific landing technique such as parkour roll (*Croft, Bertram, 2017*), jump performances (*Grosprêtre et al., 2017*), Risk factors (*Da Roca et al., 2014*), injury rates (*Wanke et al., 2013; Rossheim, Stephenson, 2017*). While there is little research about Parkour in general, there is even less studies that are attempting to compare Freerunners with other athletic or non-athletic populations. Most literature, reviewed prior to this study available at the time to the researcher, have been trying to assess parkour landing with non-parkour landing technique (*Standing, Maulder, 2015*), impact absorption between parkour techniques and traditional landings (*Puddle, Maulder, 2013*) and postural control between traceurs and recreationally active subjects (*Jabnoun et al., 2019*). Some studies have been comparing Freerunners and Gymnasts performance (*Seyhan, S. 2019*) or effects of parkour training on youth development in other sports (*Strafford et al., 2018*) with Czech researchers trying to establish parkour-specific skills assessment for use within Parkour industry (*Dvorak et al., 2018*). It appears that there is lack of sufficient research in unilateral dynamic stability between parkour and non-parkour population, as, to the best knowledge of the researcher available at the time of writing this study, there is no research available on unilateral dynamic stability on Freerunners apart from isolated case studies (*Gilsing et al., 2021*) or as progression mark of stability training within Parkour group (*Zarei et al., 2019*). Furthermore, there is no comparison with athletic or non-athletic population scores in unilateral dynamic stability tests. Unilateral dynamic stability tests such as Star Excursion Balance Test (SEBT) or HOP Test series are reliable and proven methods of assessing dynamic stability in athletic and non-athletic populations (*Fitzgerald et al., 2001; Powden et al., 2019*). Such tests can be used as screening tools to examine individual's risk of injury (*Plisky et al., 2006*), determine whether this person is ready to return to the activity, or detect weak points in their movement thus contributing to better understanding given athlete condition.

Due to their relative simplicity and reliability, SEBT and HOP Tests have been chosen for this research.

Star Excrusion Balance Test has been widely researched as an injury screening tool (*Gribble et al., 2012*), and proved to provide at least similar reliability levels as its predecessor, Y Balance Test in same directions with slightly further anterior reach (*Coughlan et al., 2012)*, while providing 5 additional directions in which participant can be assessed, increasing the complexity of the movement. There is strong evidence to support that SEBT can be used as a predictor of lower extremity injury (*Plisky et al., 2006*) and its results can be safely compared with norms, as this test has been proven to have extremely high inter-rater reliability by both single studies (*Gribble et al., 2013*) and systematic reviews (*Powden et al., 2019*). SEBT also excels in inter- rater reliability with supporting evidence (*Onofrei et al., 2019*; *Powden et al., 2019*).

Along with SEBT, the evidence behind effectiveness of HOP Test series is outstanding as well. HOP Test series consist of 4 tests- single hop, triple hop, crossover hop and timed hop which measure distance covered in the first three, and time for 6m single leg jump sprint. Tests are conducted by using 6m tape with start and finish point. These tests can be used as a predictor of lower limb strength and power (*Hamilton et al., 2008*), and have been proven as reliable tools in predicting lower limb injuries (*Fitzgerald et al., 2001*) by being included in pre-season test battery (*Guild et al., 2021*). However, research conducted to critically assess the effectiveness of all hop tests revealed that out of all 4 timed hop test scores tend to reach contralateral leg scores in the quickest way and later hypothesized that his might not be correlated to knee stability, but rather due to factors such as familiarisation of the test, as timed hop does not require a full stable stop from participant. Davies, *et al.,* (2019) later reassured that reliability of all 4 tests is very good, however, suggested that no more than 2 tests should be used at a time (*Davies et al., 2019*).

During literature search, the author reached a conclusion that research surrounding the topic of balance and stability in Parkour is focused on landing and its characteristics, or performance comparison between Parkour athletes and other populations. Maldonado *et al*., (2015) in his study "Evidence of dynamic postural control performance in parkour landing" have been assessing the time to stabilisation and ground reaction forces between Parkour practitioners and untrained participants. Maldonado *et al*., (2015) have pointed out that Parkour athletes use unique landing technique, utilizing toe only landing (so-called "precision" landing in parkour community) and wanted to check how this type of landing compares to traditional "heel-toe" landing type utilized by rest of the population. During this study, researchers discovered that Traceurs produce less Ground Reaction Force (GRF) upon landing, as well as achieving lower Time To Stabilization (TTS) than untrained participants; suggesting that Parkour landing technique should be further researched (*Maldonado et al., 2015*). This study is relatively short, and has narrow focus on the researched area, as GRF and TTS values alone do not present useful information for Parkour athletes or coaches, as authors stated that they will use the data to work within robotic framework with no real summary provided for people from Parkour industry. Maldonado *et al.,* (2018) conducted similar study about landings in Parkour, however on this occasion, the authors looked at kinematics of precision landing and compared them with untrained landings. Data analysis revealed significantly longer landing phase in Parkour athletes than in untrained group, which led to greater knee and hip flexion during precision landing, leading to decreased joint torques and therefore to lower GRF than in untrained participants. Study has been summarised with training and warm up recommendations for parkour coaches to focus on "softness" of their students landings, as higher joint angles may contribute to lower risk of patellar tendionopathy (*Bisseling et al., 2007*), which extended the information from the study mentioned before. However, both studies were assessing landings from only as high as 60cm, excluding bigger heights from the study, which are much more common during parkour trainings due to the safety of untrained participants (Maldonado *et al., 2018*). A study by Dai *et al.,* (2020), have performed kinematic analysis of Parkour landings from 0.9, 1.8 and 2.7m, with the same findings and suggestions that precision landings should be implemented in athletic populations and military personnel (Dai *et al., 2020*).

Maldonado *et al.,* 2018 and Dai *et al.,* 2020 have presented measures of GRFs and associated them with higher joint angles in parkour landings, translated to softer and less joint stressful landings. Standing and Maulder, (2015) hypothesized that sound is also associated with lower GRF in Parkour, as common practice in Parkour trainings is to label "good" landings as silent, and "bad" landings as loud, which never has been observed in any other sport or physical activity. Results of this study have shown that sound level of landing is directly linked to the amount of GRF produced by landing person (Standing and Maulder*, 2015*), further confirmed previous studies conducted in this field (Puddle and Maulder*, 2013*), and correlate to the findings made in studies conducted on general population (*Wernli et al., 2016*).

While landing studies in Parkour provided scientifical community with important information and analysis of kinematics of Parkour athletes, only a few comments with future recommendations were made, with only Maldonado *et al.,* 2018 making comments about possible injury implications for Parkour athletes. Another big point to consider is the fact that only landing has been assessed, with no further investigations made in field of what might contribute to such differences between Parkour athletes and non-Parkour populations. In Maldonado *et al.,* (2015) study “Evidence of dynamic postural control performance in parkour landing” they suggested that Parkour practitioners have better postural control and balance compared to untrained participants, just by looking at GRF and TTS scores. While it is logical to think that better landing performance is associated with better control, stability and balance of an individual, there is no evidence to support that, and no one to this date, to the best knowledge of the author, has ever tried to compare dynamic lower limb stability between Parkour and non-Parkour groups.

An important point to notice is that two articles have been found that tried to compare Parkour and non- Parkour populations with stance tests. Jabnoun *et al.,* (2019) in “Postural control of Parkour athletes compared to recreationally active subjects under different sensory manipulations: A pilot study” tried to compare bipedal, and unipedal stance between Parkour and non-Parkour group by measuring centre of pressure area (CoPa) in different postural conditions- with eyes open and closed, and on firm/foam surfaces. In this study, Jabnoun *et al.,* (2019) hypothesised that Parkour athletes would present better postural control than recreationally active participants with and without vision. This study assessed double and single leg stance on platform with foam block and firm platforms with both eyes open and closed. The results showed that Parkour participants had smaller CoPa in both conditions, with exception being bipedal stance on firm surface with eyes open. This study has produced very interesting results and Jabnoun *et al.,* (2019) have produced impressive analysis with broad discussion that these results are associated with much bigger difference in surfaces trained on by Parkour athletes, which consisted of firm, soft, metal, wooden and concrete surfaces that might have trained proprioceptive system to the point where Parkour athlete is less dependent on visual cues, thus giving him much better postural control and surface adaptation mechanisms. However, whilst assessing unipedal stance, the authors only limited the study to dominant leg, which might have had an impact on the results due to the unknown performance of the non-dominant leg in both groups (*Jabnoun et al., 2019*).

Similar, but entirely bipedal focused study has been conducted in 2020 by Veneroso *et al.,* (2020). This study focused entirely on the double legged stances, assessing bipedal, semi-tandem (one leg placed half of the feet in front of the back foot), and parkour specific stance (bend knees without varus/valgus collapse with forefoot stance), with broader selection of data analysed (velocity, amplitude, and power spectrum of CoP). The study results correlate with Jabnoun et al. (2019) findings i.e., that Parkour athletes achieved better results in postural control, and with wider selection of stance tests and variables compared, more detailed prescription about Parkour athlete stance have been assumed- Traceur requires less postural commands and do not sway in the extent non-trained participant does (*Veneroso et al., 2020*).

Both reviewed articles tried to assess balance in Parkour athletes in positions that are much easier applicable to non-Parkour populations than comparison of sport- specific with traditional landing techniques, or postural control of participants during landings. Their results only focus on bipedal stance and its variations which is the most stable and safe posture a human being can perform, with even authors stating that differences lie mostly in sport- specific positions that only Parkour athletes perform on daily basis. This factor, a unique sport-specific adaptation that only one of the assessed groups is really trained in could have had big impact on the results of the study.

With double leg balance being relatively easy to assess, and the tests such as One- Legged Stance test or Sharpened Romberg (Tandem stance) test being rather used in elder than sport populations due to the functions they assess- which is ability of participant to maintain stance with eyes open/ closed tend to be related closer to activities of daily living rather than dynamic balance that is required in high-demand sport such as Parkour (*Franchignoni et al., 1998*). Postural control results could be hypothetically connected to better sport performance by linking lower amounts of sway and smaller CoPa amplitudes with better dynamic balance performance in Parkour thus suggesting that recommendation of Parkour training in different athletic and non-athletic populations might improve their balance. However, it is important to point out that studies comparing postural control are comparing the least dynamic part of human movement which is stance. Dynamic balance is extremely important in any physical activity, as balance screening tests have the ability to predict lower limb injuries by linking weak scores with injuries in athletes (*Guild et al., 2021*), or predict performance (*Hamilton et al., 2008*) and lack of any data in this field considering growth of Parkour industry and increasing amount of attention this discipline receives as sport and subculture creates insufficient database for present and future Parkour coaches, and scientists wanting to conduct further studies in fields of Parkour performance, biomechanics or sport related injuries.

<u>Limitations</u>

Literature review for this study came across couple of limitations.

The biggest limitation that might have an impact on validity of the results is lack of research in the field of study. Due to the lack of supporting literature, some readers may find references insufficient. However, it is important to consider that here is strong possibility that research related to unilateral dynamic balance in Parkour has been done, but has not been released yet, or even that this study is first of its kind. This might be due to young age of the sport and people that are involved in it, thus there might not be many people with funds and possibilities to research every aspect of the sport, leading to limited number of resources for scientists to work with.

Another limitation to point out is the availability of already limited amounts of data. During the review, only two articles that used HOP tests in Parkour have been found- one of them described a case study of Parkour athlete with anterior ankle impingement and used triple HOP Test as screening tool in Return to Sport (RTS) protocol. Article with abstract available on jospt.org was inaccessible to the institution (*Gilsing et al., 2021*). Second article used Y-Balance test and triple HOP test as assessment tool for pre- and post-exercise programme results comparison, however the only available language to read this article in was Iranian, excluding it from this research (*Zarei et al., 2019*).

Summary and Hypothesis

During research review for this study, lack of unilateral dynamic balance assessment of Parkour athletes sparked an interest to fulfil this gap with data that could be further used for future Parkour related research. Out of different parts of Parkour research, studies mentioned above were the closest ones that came to the topic of interest. During database search no research similar to the topic that was assessed in this study has been found, with closest balance assessments being either landing stability studies (*Maldonado et al., 2015; Maldonado et al., 2018; Dai et al., 2020; Standing, Maulder, 2015*) or stance and postural control related studies (*Jabnoun et al., 2019; Veneroso et al., 2020*). While both topics are extremely important in terms of analysis of Parkour as a sport, all of the literature reviewed above has been limited to assessing Parkour and non-Parkour populations in Parkour-specified activities (landings), or relatively safe stance assessments. None of the studies have tried to compare Parkour and non-parkour participants in a study that compares these groups while using a test that has wide spectrum of available database and is not limited to just one discipline, while apart from wider audiences, providing Parkour coaches, Physiotherapists, or other scientists with expansion of image about Parkour. This opportunity can be provided with unilateral dynamic stability tests as they are widely used in athletic and non-athletic populations in almost every instance, thus the purpose and focus of this research. Based on the results of literature reviewed, the following hypothesis has been formed: Parkour athletes would achieve higher scores in both SEBT and HOP Tests.

Methods

Participants

The original sample size in the study was supposed to be n=20, with 5/5 male/female Parkour athletes and 5/5 male/female non-Parkour athletes dictated by similar sample sizes of the studies reviewed (*Maldonado et al., 2018; Dai et al., 2020; Jabnoun et al., 2019*). However, due to the transport and time limitations, female athletes were not able to make their way from London to Bedford Campus, Bedford, and considering the lack of female athletes in the area, the female groups had to be removed from the study.

Two groups of 5 male participants have been required for this study, with 5 of them being Parkour athletes, and 5 being physically active in different sport discipline/ physical activity, creating a sample size of n=10. Every participant had to be a male between 18-29 years old, being involved in either Parkour or any form of physical activity/ sport on any level for at least 6 months prior to the study, at activity frequency meeting ACSM Guidelines (*Garber et al., 2011*). Every participant had to have BMI value of healthy adult between 18.99 to 24.99, without having acute or chronic lower limb and lower back injury (i.e., ligament sprain, muscle tear, tendon ruptures, fractures, non-specific low back pain, intervertebral disc conditions), cardiovascular or respiratory conditions (i.e., asthma, anemia, heart conditions, hypertension, COPD), surgeries (i.e., joint arthroplasty) for at least 6 months before receiving Health& Screening Questionnaire. Due to the COVID pandemics still present at the time, additional exclusion criteria were being infected by COVID for at least 4 weeks prior to the study (please see Appendix A& B).

This study has been approved by the University of Bedfordshire Ethics Board, and every one of the participants has filled in Consent Form and Health and Screening Questionnaire after seeing study information sheet and being verbally informed about every aspect of the data collection (Appendix C).

Normative data of participants (age, height, body mass) has been collected on testing day 1, with Parkour group n=5, mean age 23.4±3.01 years, mean height 1.75±0.09m, mean body mass 72.02±11.56, mean BMI 23.20±1.54 kg/cm^2, and physically active group n=5, mean age 20.8±0.75 years, mean height 1.80±0.05m, mean body mass 77.06±7.10, mean BMI 23.82±2.29 (Appendix D).

Data regarding the study and participants have been stored on researcher personal laptop in password- protected folder and would be deleted after assessment of this research would have been completed.

Procedures

Two dynamic stability tests have been used in this study. The SEBT test has been performed by participant trying to reach furthest possible distance with his non-weight bearing leg in 8 different directions, which are assessed in following order: Anterior, Anterolateral, Lateral, Posterolateral, Posterior, Posteromedial, Medial, Anteromedial. Layout of the test looks very similar to star, as there are 4 tapes used which are crossing themselves in single center point and are separated by 45° angle between each other. Participants were to reach furthest possible distance with non-weight bearing leg while maintaining balance on weight-bearing leg. If participant supported himself with reaching leg at any point during the reach, the reach had to be repeated. Distance between centre point and reach point for each leg has been measured (Powden *et al.,* 2019). This test assesses furthest possible distance that an individual can reach in centimeters. Test has been already set up during previous practicals happening at the University. Second test used was single leg HOP test series. This test consists of single, 6m long line and two 1m long lines placed perpendicular to mark start and finish line, with measuring tape placed parallel, 50cm next to the line. Lines were made by sticking white tape to the floor. This series of tests consist of 4 different assessments of lower limb stability, which are: single HOP- participant jumps as far as possible on one leg, triple HOP- participant has to cover longest distance possible during 3 consecutive jumps, crossover HOP- participant has to jump 3 consecutive times, while simultaneously jumping over marking line during every jump. These three tests are considered valid when participant does not lose balance during activity and lands firmly without loss of balance during landing. 4th test is 6-meter timed HOP test- participant task is to jump 6 metres on one leg as fast as he can with no restrictions to number of jumps, without losing balance during activity. These tests assess participant ability to maintain balance during jumping, landing and direction changes on single leg (Fitzgerald *et al.,* 2001). Results of first three HOP tests are going to be presented in metres (m), and for the timed HOP test, results will be presented in seconds (s).

For the purpose of testing and normative data collection, following equipment has been used: 8m of white tape, stopwatch (Quantum 5501, Cranlea, UK), weigh scales (Seca 813 Robusta, HaB Direct, UK), stadiometer (Harpender, HAR- 98.602, Holtain, UK), anatomical measuring tape (HaB Direct, UK), 30m measuring tape (RST Tools, HaB Direct, UK).

Each testing session lasted for 60 minutes. Testing days were randomized, relied on the availability of the room. Only one participant per group was tested, with next participants following. All participants were advised to stretch post activity. There was unified warm up protocol for all participants, which included: 5 minutes of jogging with RPE beginning at 5 and slowly increasing to RPE 7, mobilisation of the joints: ankle circles - 20 circles clockwise/ counterclockwise per leg, squats - 3 sets of 10 squats, hip circles - 20 circles clockwise/ counter clockwise. Followed by muscle activation exercises: calf jumps - 3 sets, 10 repetitions per set, lunges - 3 sets, 10 repetitions per set. Followed by dynamic stretching: leg swings - 3 sets of 10 swings per leg, dynamic lunges - 3 sets of 10 repetitions per set.

Testing order for SEBT and every single HOP test was randomized for each session to avoid participant adaptation in this order:

Session 1: Normative data collection, SEBT, Single HOP test, triple HOP test, crossover HOP test, 6-meter timed HOP test

Session 2: Single HOP test, SEBT, crossover HOP test, 6-meter timed HOP test and triple HOP test

Session 3: 6-meter timed HOP test, triple HOP test, crossover HOP test, single HOP test and SEBT

Data Analysis

IBM SPSS 26 statistical analysis programme was used in this study, with Microsoft Excel 2204 used to collect and store data. Since the aim of this study was to compare mean results from each test between two independent groups (Parkour and physically active), Independent

T-Test has been chosen to perform statistical analysis, with Levene's test to assess homogeneity of variances and data presented as Mean ± SD. Normal distribution of data has been assessed by producing Q-Q Plot for every result. SEBT results has been presented in centimeters (cm) and HOP Test results have been presented in meters (m) for distance-covering tests and seconds (s) for timed HOP test. Statistical analysis was conducted based on each participant's average of all 3 trials in every test, with full dataset available in Appendices D, E and F.

Results

Overview

In this study, full range of 8 SEBT reaches- Anterior, Anterolateral, Lateral, Posterolateral, Posterior, Posteromedial, Medial and Anteromedial has been collected from each leg stance. This resulted in 16 conducted T-tests comparing Parkour and non- Parkour scores from 8 reaches in right versus right and left versus left leg reach. Full range of HOP Tests scores have been analysed with left versus left and right versus right leg scores compared in single hop, triple hop, crossover hop and timed hop tests requiring 8 independent T-tests to be ran, with total number of analytic tests used being 24.

Star Excursion Balance Test scores

SEBT Right leg reach

During right leg reach analysis, Parkour group have achieved greater average scores in Anterior (Parkour= 80.99 ± 7.38 cm vs non-Parkour= 79.6 ± 9.79 cm), Lateral (87.79 ± 4.12 cm vs 83.62 ± 8.89 cm), Posterolateral (95.2 ± 2.8 cm vs 84.42 ± 10.65 cm), Posterior (99.46 ± 7.44 cm vs 85 ± 9.45 cm), Posteromedial (90.4 ± 4.65 cm vs 76.67 ± 11.26 cm), and Medial (75.8 ± 7.5 cm vs 68.25 ± 17.13 cm) reaches with non-Parkour group scoring higher only in Anterolateral (82.76 ± 4.9 cm vs 83.94 ± 9.68 cm) and Anteromedial (72.74 ± 5.83 cm vs

75.14 ± 12.04 cm) reaches (see Figure 1 and Appendix D). There were no statistically significant differences in Anterior reach (t_8= 0.249, P = 0.810), Anterolateral reach (t_8= -0.242, P = 0.815), Lateral reach (t_8= 0.951, P = 0.380), Posterolateral reach (t_8= 2.190, P = 0.060), Medial reach (t_8= 0.903, P = 0.393) and Anteromedial reach (t_8= -0.402, P = 0.702). The only directions in which significant differences has been reported were Posterior reach (t_8= 2.688, P = 0.028) and Posteromedial reach (t_8= 2.518, P = 0.036) (Appendix F).

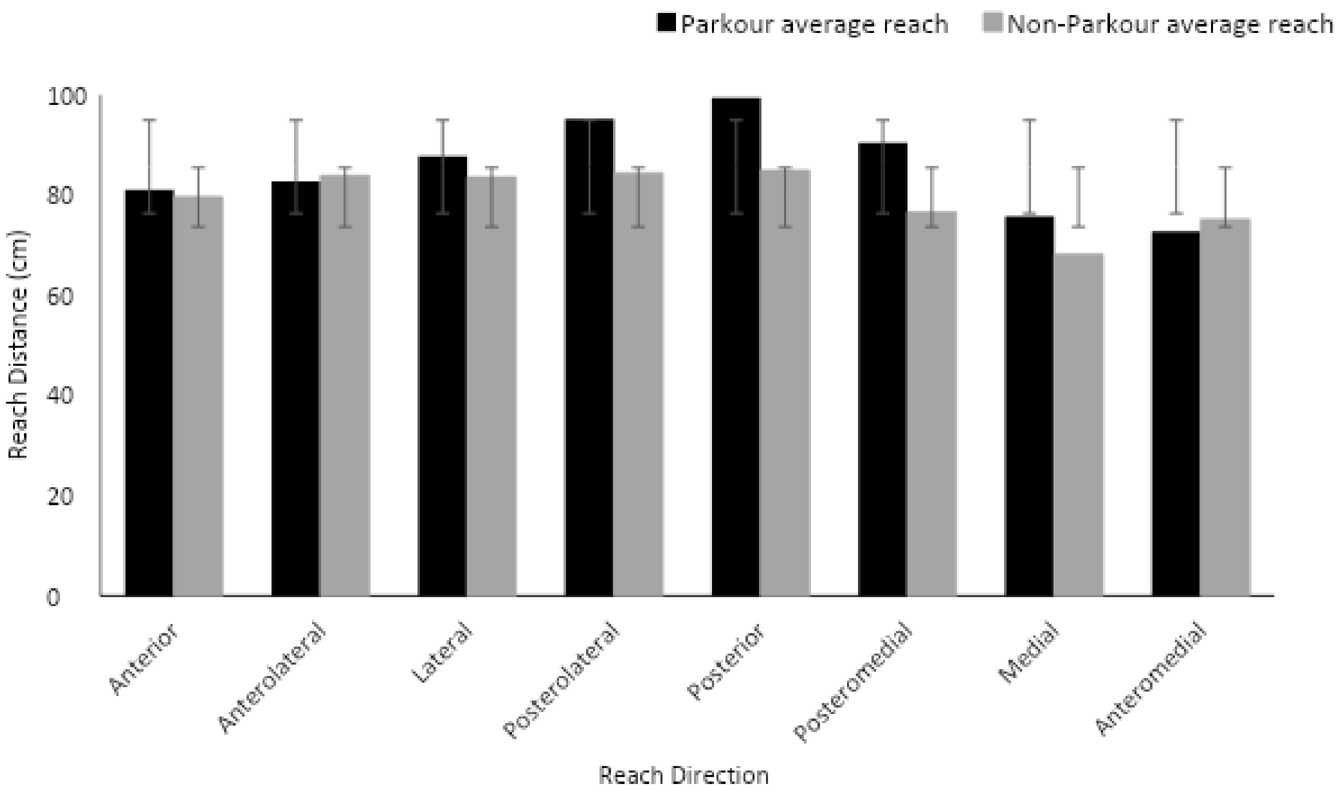

Figure 1: Parkour and non-Parkour right leg reach average scores in SEBT.

SEBT Left Leg Reach

During left leg reach analysis, Parkour achieved higher scores in Posterolateral (94.86 ± 3.21 cm vs 88.42 ± 12.4 cm), Posterior (98.45 ± 7.07 cm vs 86.34 ± 12.55 cm), Posteromedial (92.53 ± 9.35 cm vs 83.38 ± 13.31 cm) and Medial (80.09 ± 10.26 cm vs 66.9 ± 16.94 cm) reaches with non-Parkour group scoring higher in Anterior (80.8 ± 9.07 cm vs 84.08 ± 10.2 cm), Anterolateral (80.9 ± 5.24 cm vs 87.45 ± 9.64 cm) and Lateral (85.36 ± 5.5 cm vs 86.01 ± 11.01 cm) reaches, with Anteromedial reach having roughly equal scores for both groups (69.79 ± 9.72 cm vs 69.72 ± 7.38 cm), which has been presented on Figure 2 (Appendix D). No significant differences were observed in any of the directions for the left leg reach: Anterior (t_8= -0.537, P = 0.606), Anterolateral (t_8= -1.328, P = 0.221), Lateral (t_8= -0.118, P = 0.910), Posterolateral (t_8= 1.123, P = 0.294), Posterior (t_8= 1.880, P = 0.097), Posteromedial (t_8= 1.257, P = 0.244), Medial (t_8= 1.489, P = 0.175) and Anteromedial (t_8= 0.013, P = 0.990)

(Appendix F).

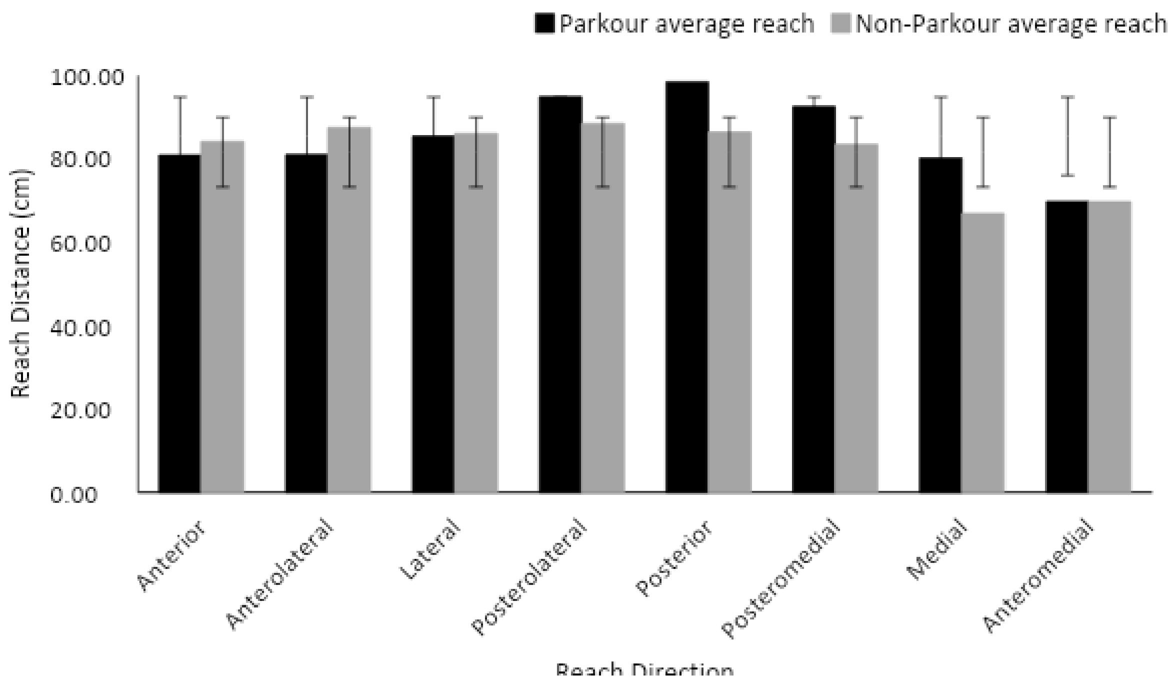

Figure 2: Mean reach distance in every direction in both groups for left leg reach in SEBT.

<u>*HOP Test series scores*</u>

HOP Test left Leg Scores

Parkour group had achieved higher scores in every HOP test during left leg assessment, with average scores presenting as: Single HOP (2.11 ± 0.13 m vs 1.54±0.21 m), Triple HOP (6.64 ± 0.69 m vs 4.56 ± 0.85 m), Crossover HOP (6.56 ± 0.63 m vs 4.03 ± 1.15 m) and faster average times in Timed HOP (1.86 ± 0.25s vs 2.06 ± 0.3s), presented in Figure 3 (Appendix D). Independent T-test conducted revealed that there was a significant difference in Single (t_8= 5.053, P = 0.001), Triple (t_8= 4.219, P = 0.003) and Crossover HOP (t_8= 4.316, P = 0.003), however no significant difference observed in Timed HOP test (t_8= -1.117, P = 0.296) (Appendix F).

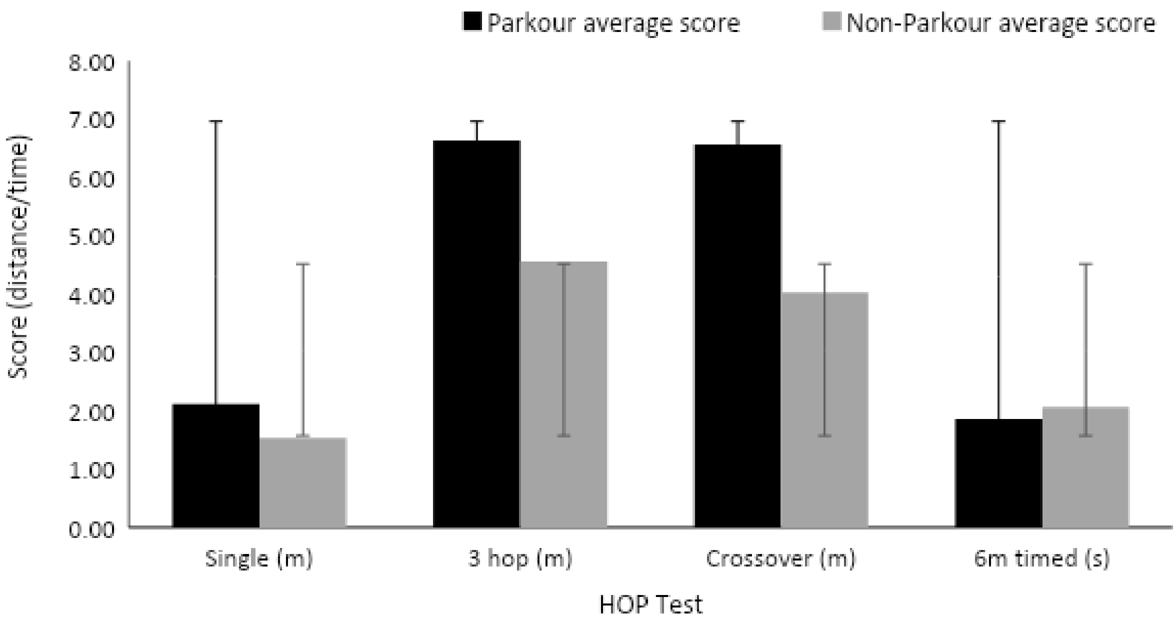

Figure 3: Mean HOP Test results for both group left leg assessment

HOP Test Right Leg Scores

Right leg assessment revealed that Parkour group scored higher average scores in each HOP Test again, with average results presenting as: Single HOP (2.07 ± 0.16 m vs 1.58 ± 0.8 m), Triple HOP (6.59 ± 0.72 m vs 4.78 ± 0.56 m), Crossover HOP (6.52 ± 0.76 m vs 4.25 ± 1.18 m) and Timed HOP (1.9 ± 0.25 s vs 1.88 ± 0.25 s), available for review in Figure 4 (Appendix D). There was a significant difference in Single HOP (t_8=6.023, P< 0.001), Triple HOP (t_8= 4.403, P = 0.002) and Crossover HOP test (t_8=3.608, P = 0.007). However, no significant difference has been noticed in Timed HOP test (t_8= 0.090, P = 0.931) (Appendix F).

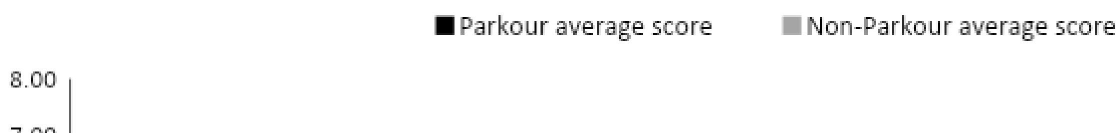

Figure 4: Average scores of Parkour and non-Parkour participants in right leg HOP Tests.

<u>*Summary*</u>

Results presented above do not exactly link with hypothesis of this study, particularly in SEBT scores, where in mainly posterior directions Parkour group scored higher average reaches compared to non-Parkour, however out of 16 analyses conducted, only 2 showed statistically significant difference (Right leg Posterior and Posteromedial reaches). However, in HOP Tests, Parkour group has better average scores than non-Parkour in every test, with distance tests (Single, Triple and Crossover) scores having statistically significant difference compared to Timed HOP test. Complete SPSS outputs and Datasets along with Excel spreadsheets containing full list of scores, Q-Q plots and T-test results for both tests are available in the appendices D, E and F.

Discussion

The aim of this study was to assess unilateral lower limb dynamic stability of Freerunners and compare the results with non-Parkour group using SEBT and HOP Tests, with the hypothesis stating that the Parkour group will score better in both tests. The results of the study do not present the evidence to fully confirm the hypothesis. As Freerunners indeed achieved much better average scores in all HOP Tests in both legs, however in SEBT, Parkour group achieved higher average scores in posterior reaches only along with Anterior, Medial and Lateral right leg reach and Medial left leg reach, with physically active group scoring better average scores in the rest of the directions. During statistical analysis, Single, Triple and Crossover HOP Tests showed statistically significant differences, with Timed HOP not providing the same outcome. T-Tests conducted on SEBT provided interesting results. According to the analysis, only right leg Posterolateral and Posterior reaches are significantly different between Parkour and non-Parkour group, with rest of the directions having no statistically significant differences. These results will be discussed later in this section, along with analysis of why Parkour has had better scores in HOP Tests while not showing significantly better results in SEBT.

SEBT results do not confirm the hypothesis of this study with results not showing dominance of Parkour above non-Parkour group, with only clear advantage being in all Posterior reaches average scores. This does not correlate with findings and theories of previous authors that tried to assess balance of Parkour practitioners during landing (*Maldonado et al., 2015; Maldonado et al., 2018; Dai et al., 2020; Standing, Maulder, 2015*), or control during stance (*Jabnoun et al., 2019; Veneroso et al., 2020*), where in both cases, clear results were obtained. It is important to mention that both landing balance or postural control studies, have assessed parkour- specific movements and adaptations, where SEBT due to the protocol not allowing any sport-specific adaptations to occur, thus excluding sport specificity impact on results. Considering this characteristic of the test and the significance of the results, one might assume that Parkour practitioners do not possess greater stability than other sporting populations. However, it is important to remember that average scores showed promising results in posterior parts of SEBT with some anterior and lateral-medial reaches also having higher averages. This can lead to two conclusions. Firstly, as mentioned above, that there is no significant difference between Parkour and non-Parkour group, concluding that the Parkour population do not possess extraordinary balance in lower extremity compared to other populations. Secondly, results given (higher average scores with some parts being statistically significant) combined with the number of participants being 5 per group; inexperience of the researcher and lack of previous studies in this field, would get taken into consideration, suggesting further research is warranted to determine whether Freerunners do or do not possess better dynamic stability than other sport populations.

Insignificant results could indicate that results could have occurred by chance. However, higher average scores in posterior reaches present an interesting point to analyse, considering that rest of the scores were either closely matched or smaller in Parkour group. Now if the HOP Test scores are brought into the discussion, with Parkour groups achieving significantly higher scores in all the distance-covering tests, higher average scores in posterior reaches in SEBT could be linked to higher distances covered in HOP test, as during single leg jumping, non-jumping leg takes part in the jump producing momentum by swinging anteriorly from the back of the body. The position in which human body is at this moment is very similar to positions that occur during Posterior, Posterolateral and Posteromedial reach, with trunk flexed, take off foot, hip and knee in flexion, ankle in dorsiflexion and swinging leg extended. Parkour being a sport where single leg takes offs occur at significantly higher rate than other sport disciplines could mean that Freerunners had much more practice in variety of single leg positions during takeoffs, direction changes or landings compared to non-Parkour practicioners. However, due to statistical insignificance of the results and only average scores being different, this statement can only stay in sphere of speculations until further research would be conducted.

While SEBT scores have turned inconclusive, HOP Test analysis showed a clear difference between Parkour and non-Parkour group. Parkour athletes have shown to cover much greater distances in Single, Triple and Crossover HOP tests. The only test where no significant difference has been found was Timed HOP Test. This can be supported by the idea Parkour athletes' main priority during training is to increase jumping distance, not the speed at which these jumps are performed (*Gosprêtre, Leppers., 2016*). Greater distance covered in HOP Tests can be associated with two main factors: Ability to jump far, i.e., being able to produce high amounts of power in short time, and secondly, being able to land the jump and fully stop without losing balance during landing. Parkour practitioners can be considered to have higher level of functional fitness than the rest of the population (*Marchetii et al.,* *2012*), especially when considering jumping performance of a Traceur (*Grosprêtre, Ufland, Jecker., 2018; Grosprêtre, Leppers., 2016*), in which results of distance HOP Tests tend to confirm. There could be a couple of contributing factors to this statement, beginning with high eccentric focused training done by Traceurs that results in high eccentric forces being produced by lower limbs due to frequency and intensity of landings performed (*Grosprêtre, Leppers., 2016*), as eccentric contraction is well known to be producing highest force outputs among all types of contractions (*Roig et al., 2008*), thus contributing to jump performance.

Another factor that can be linked to the advantage on jump performance of Parkour athletes are results of the study conducted by Grosprêtre *et al.* in 2018, where the authors assessed maximal isometric plantar flexion force and rate of torque development by stimulating posterior tibial nerve, discovering that Freerunners excelled in both parameters, linking the findings to better spinal excitability compared to control group (*Grosprêtre et al. 2018*). Evidence linking athletic performance and balance could also be an explanation why the Parkour group achieved greater results. Cross-sectional studies *(Hrysomallis., 2011*) found that basketball players, swimmers, football players and gymnasts have been presented as athletes with the best balance ability, within Parkour athletes' performance has been compared and deemed roughly equal in some areas of gymnastics (*Seyhan et al., 2019*). Therefore, it is safe to assume that Parkour athletes would present similar balance scores. Higher joint angles with following lower peak GRF during landings in Parkour practitioners compared with untrained participants (*Maldonado et al., 2015; Maldonado et al., 2018*) are associated with better force absorption. During single-leg landing, lower extremity has shown bigger knee joint movements in frontal plane, especially in valgus direction (*Shin et al., 2009*). Knowledge about single leg landing biomechanics and Parkour characteristics can lead to an assumption that higher force dissipation abilities in

Freerunners allows them to jump further, as force production increases with jump length which leads to higher kinetic energy amounts needed to absorb during landing. While in Timed HOP Tests this might not be a deciding score factor, as participant do not have to stop, in distance HOP Tests, better force dissipation abilities may favour higher distances due to load tolerance of the lower limb, further linking stability with jumping performance. Whilst balance showed a direct correlation with performance, there are also studies stating that unilateral balance and performance are not directly connected. Research suggest that there are some sings of linkage between each other, however the topic is complex and this field should receive more research (*Lockie et al., 2015*), putting superior performance linked with better balance in Parkour group open to debate.

There is also evidence linking plyometric based training and jump performance (*Ramirez-Campillo et al., 2020*), which has been explained in another study as adaptation of the tendons to stretch-shortening cycle along with no changes in tendon stiffness, with joint stiffness reported to increase by plyometric training, which can be linked to usage of elastic energy during jumping, with weight-based training providing opposite results (*Kubo et al., 2007*). This provides a statement that plyometric training is a great tool in increasing jump performance, which could further contribute towards explanation why Parkour athletes achieve higher scores in jumping tests. However, following the reports of plyometric training research, there is evidence that plyometric training increases joint stiffness (*Kubo et al., 2007*), which, as discussed before, is not a trait that characterises Parkour athletes as they tend to conduct very soft landings with high joint angles and low joint peak torques (*Maldonado et al., 2018*). There could be a possibility that Traceurs adapted both stiffness of plyometrics and softness of their landings, creating a versatile lower limb that is able to adapt to changing environment.

Important point to consider is also adaptation of Parkour practitioners to jumping. Research has shown that Traceurs exhibit greater arm swing and shallower take off angle than untrained individuals (*Grosprêtre, Ufland, Jecker., 2017*) and softer landings, allowing for better force absorption (*Maldonado et al., 2018; Dai et al., 2020*). Parkour tends to focus naturally on both distance and precision of the landings with arm swinging contributing to as much as 30% of the distance and take off angles used by Parkour athletes being surprisingly close to calculated optimum take off angles (*Grosprêtre, Ufland, Jecker., 2017; Wakai, Linthorne., 2005*). This has been explained as arm swinging would have changed joint angles in lower extremity, allowing for better force production, muscle activation and greater torques resulting in further distance covered. Another contribution of arm swing in jumping is additional stability and control arms grant by swinging them back during landing phase, levelling the body for landing, allowing for shallower take off angle, more horizontal force development and contributing to greater hip extensors activation (*Ashby, Delp., 2005; Ashby, Heegaard., 2002*). With further jump distances covered by Parkour athletes compared to non-Parkour and untrained individuals revealed during HOP tests in this study and better force production and muscle activation patterns, careful assumption can be made that contribution of arm swing to jump distance is higher in Parkour practitioners and can be used as another explanation of better results in HOP Tests.

Additional information that might be connected to superior distance covered in HOP Tests by Parkour athletes is the type of footwear worn by participants. Research indicates that majority of Parkour practitioners prefer to train in shoes that offer less thick soils then typical footwear worn in gym or running environments, such as running sneakers or flat, skate-type shoes during their training with rubber sole granting maximal grip levels possible (*Grosprêtre, Khattabi et al., 2022*). During data collection for this study, results of this research has been deemed valid, as 3 out of 5 participants admitted using Nike SB Janoski, a popular skate trainers with flat sole as their main training footwear, with other two following with popular brand joggers, compared to the non-parkour participants in which footwear differed from person to person. There has been research done on comparison of thickness of footwear sole compared with results of GRF in single-leg landings, which stated that sole thickness is directly correlated with GRF and vertical load rates during landings, with thinner soles resulting in lower landing forces and thus, better dynamic stability (*Bowser et al., 2017*). The explanation behind such statement can be found in increased prioproceptive and sensory inputs to the foot through thin sole compared to thicker footwear. Best results were attained when participants were not wearing any footwear, suggesting that neuromuscular system receives the best sensory feedback while barefoot, enabling the most efficient stabilisation to occur. No relationships between footwear condition and jumping performance or landings have been found (*Harry et al., 2015*).

<u>Summary</u>

Results of this study have partially confirmed the hypothesis, with Parkour group only achieving significantly greater results in distance HOP Tests. SEBT tests results returned inconclusive, however, mean scores provide interesting findings in regard to reaching distance compared with non-Parkour participants. However, the main aim of this study- producing data about Parkour athletes results in lower limb dynamic stability tests- can be considered accomplished. Current paucity of research in Parkour opens broad field of interpretation and rationale for the results produced, with many factors possibly contributing to scores attained. Purpose of this study was to compare scores of dynamic balance tests and possibly create a baseline for future research in this area, allowing for further analysis of Parkour. Since Parkour is relatively fresh discipline, there is no stated opinion, or at least partially completed analysis of every aspect of this sport, making rationalizing, discussing and comparing this discipline and its practitioners with other athletic, or general population difficult. Discussion about the results of this study tried to take into account as many documented factors that could contribute to the differences as possible. However, the diversity of these factors is very broad, that each explanation should rather be interpreted as recommendation of further research in the field rather than rationale and analysis of the results in given topic.

Limitations

This study is by no means perfect, and it is urgent to remind the reader about its limitations.

The main limitation, as mentioned previously in literature review, is lack of research in the area, little to no research conducted at all. This makes the rationale for this study and its findings difficult to interpret essentially providing the audience with results that can not be directly linked to certain characteristics of the sport.

Another important limitation is inexperience of the researcher, being final year Bachelors course student. While undergraduate studies provide invaluable resources and practice in conducting research, every undergraduate student, even if its final year, only begins to develop his research skills and understanding of the scientific industry. That can lead to misinterpretation of results, not accurate measurements or lack of literature finding skills, which can have great impact on the overall quality of the study.

Limitation, that could have big impact on the results is the number of participants included in the study, with n=10 participants divided into two n=5 groups possibly presenting too small and weak statistical power to produce conclusive results. Also, fact that only male participants were compared should be remembered, recommending involvement of female participants and greater numbers for future studies.

Conclusion

In conclusion, the results of this study provide data that do not completely correlate with results obtained from studies in similar areas. Due to inconsistency of the results, with SEBT scores not being significantly different, no clear statement can be provided, with hypothesis only partially confirmed. However, SEBT scores on their own, with posterior reaches being almost exclusively higher, provided interesting data that could lead to separated field of study assessing single leg performance in Parkour. HOP test results provide data that can be used to assume Parkour athletes have better dynamic balance, compared to population from other sports background. Considering the limitations of the study i.e., small number of participants creating possibility of low statistical power not good enough to conduct proper analysis, or pioneer nature of research, it is suggested to treat the following study as a pilot study and develop it further with greater statistical power rather than standalone piece of literature.

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Appendices

Appendix A: *Participant consent form:*

SCHOOL OF SPORTS SCIENCE AND PHYSICAL ACTIVITY

Bedford Campus

Polhill Avenue

Bedford

MK41 9EA

Date: xx.xx.xxxx

B. Informed Consent Form <u>(TO BE COMPLETED BY PARTICIPANT, aged over 18 years)</u>

Project title: Comparison of unilateral lower extremity dynamic stability between parkour athletes and physically active young adults.

Name of Researcher: Maciej Chrupek

Supervisor Name: Tarryn Mutch

Participant name: ……………………………………………………

Please initial box

1. I understand from the participant information sheet dated ……………………… which I have read in full, and from my discussion(s) with Maciej Chrupek I confirm that I have had the opportunity to ask questions about the study and, where I have asked questions, these have been answered to my satisfaction. ☐

2. I agree to do the following as part of the study: attend 3 training sessions to complete this project. I will have to complete 2 single leg dynamic stability balance tests which are Star Excursion Balance Test (SEBT) and HOP tests. ☐

3. It has been explained to me by Maciej Chrupek that the risks and side effects that may result from my participation are as follows: Delayed Onset Muscle Soreness, tiredness, soft tissue injures. ☐

4. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐

5. I understand that any personal information regarding me, gained through my participation in this study, will be treated as confidential and only handled by individuals relevant to the study and the storing of information thereafter. Where information concerning myself appears within published material, my identity will be kept anonymous. ☐

6. I confirm that I have completed the health questionnaire and know of no reason that would prevent me from partaking in this research. ☐

7. I agree to partake as a participant in the above study. ☐

Participant signature: …………………………………… Date: …………………………

Primary Researcher signature: ………………………… Date: ………………………..

Appendix B: *Health&Screening Questionnaire:*

F: Health Screen and Physiological Testing Questionnaire

University of Bedfordshire

Project title: Comparison of unilateral lower extremity dynamic stability between parkour athletes and physically active young adults

Participant name: ……………………………………… Sex: …………….…… Date of Birth …………….……

As an individual participating in physical activity, it is important that you are currently in good health. This is to ensure your well-being and to try and prevent confounding data. This completed questionnaire will be held in a locked filing cabinet in the Sport and Exercise Science Laboratories for a period of three years. After this time, it will be shredded. Please ask for a photocopy of this questionnaire if you require one.

Please complete this brief questionnaire to confirm your ability to participate:

1. At present, do you have any health problem for which you are:

(a)	on medication, prescribed or otherwise	Yes	☐	No	☐
(b)	attending your general practitioner	Yes	☐	No	☐
(c)	on a hospital waiting list for an injury	Yes	☐	No	☐
(d)	recovering from an illness or operation	Yes	☐	No	☐

2. In the past two years, have you had any illness or injury which required you to:

(a)	consult your GP	Yes	No	
(b)	attend a hospital outpatient department	Yes	No	
(c)	be admitted to hospital	Yes	No	

3. Have you ever had any of the following:

(a)	Convulsions/epilepsy	Yes	No
(b)	Respiratory conditions (e.g. asthma/bronchitis/ turburculosis)	Yes	No
(d)	Eczema	Yes	No
(e)	Diabetes	Yes	No
(f)	A blood disorder (including infections/viruses)	Yes	No
(g)	Head injury including concussion	Yes	No
(h)	Digestive/ Gastrointestinal problems	Yes	No
(i)	Heart problems/chest pains/ angina/heart attack/varicose vein/ embolism/aneurysm........................	Yes	No
(j)	Problems with muscles, bones or joints (e.g. arthritis/back pain)	Yes	No
(k)	Disturbance of balance/coordination	Yes	No
(l)	Dizziness / black outs / fainting	Yes	No
(m)	Disturbance of vision	Yes	No
(n)	Ear/hearing problems	Yes	No
(o)	Thyroid problems	Yes	No
(p)	Kidney or liver problems	Yes	No
(q)	Problems with blood pressure (low or high)	Yes	No
(r)	A pacemaker	Yes	No
(s)	Chronic obstructive pulmonary disease (COPD)	Yes	No
(t)	Anaphylactic shock symptoms to needles, probes or other medical-type equipment	Yes	No
(u)	Any allergies or food intolerances	Yes	No
(v)	A history of heart disease in the family	Yes	No
(w)	Been pregnant or given birth in the last 6 months	Yes	No
(x)	Rectal problems	Yes	No

If YES to any question, please describe in more detail if you wish (for example, was the problem short lived, if it is controlled, if it is re-occurring, if your doctor has given you specific information/instructions regarding the problem).

……
……
……

4. Please state what medication (if any) you are currently taking; explain briefly what the medication is for and how long you have been taking it.

……
……
……

5. Do you have any other condition or disability that you feel we should be aware of?

Yes ☐ No ☐

If yes, please briefly explain below:

……
……
……

6. Are you currently involved in any other lab activity at the University or elsewhere?

Yes ☐ No ☐

If yes, please provide details.

……
……………………………………………………

7. Please provide contact details of a suitable person for us to contact in the event of any incident or emergency.

Name: …………………………… Relationship to Participant: ……………

Telephone Number: …………………………… Work ☐ Home ☐ Mobile ☐

University of Bedfordshire

I declare that this information is correct and is for the sole purpose of giving the tester guidance as to my suitability for the test. As far as I am aware, there is nothing that might prevent me from successfully completing the tests that have been outlined to me. For any issues raised in sections 1-5 the appropriate precautions (Doctors check, medication to hand) have been taken and I am therefore still willing and able to participate in the current laboratory session as a participant. Whilst also being aware of the risks associated with the current protocol.

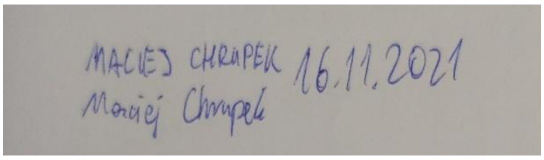
Signed (participant) ………………………………… Date………………………………

Signed (researcher) …………………………… Date………………………………

Signed (relevant staff member to check documentation) ………………………………
Date……………

If there is any change in the circumstances outlined above, it is your responsibility to tell the person administering the test immediately.

Appendix C: *University of Bedfordshire ethics board approval for this study:*

	Research supervisor: Tarryn Mutch  Date: 17/11/2021
Reviewer 1  Date: 30th November 2021	Reviewer 2 (if required) Date
School Ethics Representative (if required) Date	

Appendix D: *Excel spreadsheets containing participant normative data, full results and averages of the results used for analysis in SPSS.* ***Note:*** *Parkour group is being named "PK", and physically active group "NPK", with participant number, followed by (in full results sheet) number of trial, i.e., PK 1-1, 2, 3 refers to Parkour participant number 1, 1st, 2nd, 3rd trial.*

- *Normative data of participants:*

	age	height	mass	BMI
PK1	24	1.81	81.2	24.79
PK2	25	1.84	83.5	24.66
Pk3	23	1.73	64	21.38
PK4	27	1.81	78.1	23.84
PK5	18	1.58	53.3	21.35
NPK1	21	1.84	88	25.99
NPK2	20	1.75	76	24.82
NPK3	20	1.81	81.1	24.76
NPK4	21	1.74	73.1	24.14
NPK5	22	1.86	67.1	19.40

- *With averages± SD following:*

Age	STDev	Height	STDev	Mass	STDev	BMI	STDev
23.40	3.01	1.75	0.09	72.02	11.56	23.20	1.54
20.80	0.75	1.80	0.05	77.06	7.10	23.82	2.29

- *Full SEBT results spreadsheet, left leg reach:*

SEBT	Ant	AntLat	Lat	PostLat	Post	PostMed	Med	AntMed
PK1-1	90.5	84	88.6	98.6	92	85.1	84.7	78
2	91	82.5	88.1	100.1	93.1	83.2	86.2	79.2
3	90.2	83.7	88.9	99.3	91.8	84	85.4	77.1
PK2-1	83.5	79	91.6	96.4	109.5	106.3	93.2	77
2	83.1	78.9	91.1	95.4	110.3	108.1	91.8	76.2
3	84.3	80.1	91.4	95.9	109.6	107.3	93.3	78
PK3-1	74.2	86.8	81.6	92.2	100.2	91.6	81.5	72.5
2	75	87.4	82.1	93.1	100.5	90.3	82.9	73.7
3	74	86.9	82	92.1	100.8	91	82.6	73.1
PK4-1	68.1	72.8	77.2	91.3	96.2	85.5	63.2	54
2	69.3	73.4	77.5	90.8	96.4	85.2	73.6	54.6
3	68.4	72.7	78.1	91.2	95.7	84.9	63.1	55.1
PK5-1	87	82.5	87.3	95	93	95	73	66.6
2	86.6	81.3	87.6	96.2	94.1	94.9	73.2	66.1
3	86.9	82	87.4	95.3	93.6	95.6	73.7	65.7
NPK1-1	88.5	90	94.3	95	101.5	94.3	89	74.1
2	89	91.2	94.9	95.8	100.9	92.1	87.1	76.4
3	87.7	90.3	93.8	95.5	102	95.5	90	75.2
NPK2-1	92	97.2	96.3	104.8	94.3	97.1	77.2	77.6
2	93	96.4	96.4	105	95.1	98	78.3	78.3
3	92.1	97.3	96.7	104.3	94.7	96.4	76.1	79.4
NPK3-1	84.1	78.2	74.5	80.1	85.1	72	44.5	66.6
2	83.2	78.6	73.8	80.3	85.4	70.4	43.1	65.4
3	85	77.5	73.9	80.6	84.6	69.3	45	66.1
NPK4-1	66	76	74	72.8	68.6	67	63.9	59.5
2	67.5	76.9	74.5	73.3	69	69.4	64.9	60.9
3	66.3	76.2	74.2	73.1	68.7	68.3	63.5	59.1
NPK5-1	88.5	95.2	91	88.7	81.4	86.5	61.4	69.3
2	89.3	94.7	91.5	88.1	81.8	88.2	59.3	67.8
3	89.1	96.1	90.4	89	82	86.3	60.2	70.2

Left Leg reach

- *With means± SD:*

SEBT	Ant	AntLat	Lat	PostLat	Post	PostMed	Med	AntMed
PK1AVG	90.56667	83.4	88.53333	99.33333	92.3	84.1	85.43333	78.1
PK2AVG	83.63333	79.33333	91.36667	95.9	109.8	107.2333	92.76667	77.06667
PK3AVG	74.4	87.03333	81.9	92.46667	100.5	90.96667	82.33333	73.1
PK4AVG	68.6	72.96667	77.6	91.1	96.1	85.2	66.63333	54.56667
PK5AVG	86.83333	81.93333	87.43333	95.5	93.56667	95.16667	73.3	66.13333
PKAVG	80.80667	80.93333	85.36667	94.86	98.45333	92.53333	80.09333	69.79333
NPK1AVG	88.4	90.5	94.33333	95.43333	101.4667	93.96667	88.7	75.23333
NPK2AVG	92.36667	96.96667	96.46667	104.7	94.7	97.16667	77.2	78.43333
NPK3AVG	84.1	78.1	74.06667	80.33333	85.03333	70.56667	44.2	66.03333
NPK4AVG	66.6	76.36667	74.23333	73.06667	68.76667	68.23333	64.1	59.83333
NPK5AVG	88.96667	95.33333	90.96667	88.6	81.73333	87	60.3	69.1
NPKAVG	84.08667	87.45333	86.01333	88.42667	86.34	83.38667	66.9	69.72667
PKSTD	8.129573	4.721111	4.959659	2.912685	6.340648	8.390047	9.455472	8.717145
NPKSTD	9.146866	8.641672	9.849796	11.09772	11.23357	11.95145	15.17898	6.652665

Left Leg reach

- *SEBT Right leg reach results:*

Ant	AntLat	Lat	PostLat	Post	PostMed	Med	AntMed
94	90	91.6	96	100.5	84	83.6	76.9
92.8	91.3	92.4	95.2	101	85.1	84.1	76.2
93.5	90.4	92.1	96.3	100.3	85.6	84.3	77
79	83.5	90.5	94.2	108.2	90	73.6	71.4
78.8	82.4	91.3	94.1	108.3	90.2	74.2	72
79.1	83.7	90.2	94.5	109.1	91	73.2	72.2
77.6	82.4	90	99.8	104.4	97.5	83	75
78.4	81.8	89	98.2	104.9	97.6	82.2	74.6
77.2	81.9	89.4	100.2	103.8	98.2	82.5	75.5
73.8	76.8	84.1	94.4	91.2	89	65.4	63
74.4	77.2	83.5	95.2	91.5	89.4	66	63.2
73.9	76.7	84.1	95	92.3	88.8	66.1	62.7
80.2	81	83.2	91.6	91.6	89	73	77.7
81.5	80.9	82.6	91.1	92.2	90.4	72.5	77
80.8	81.4	82.9	92.3	92.7	90.2	73.4	76.7
86.6	87.5	89.5	91.5	92.5	92.1	75.7	79.5
85.4	88.1	89.3	92.1	93.3	92	76.3	80.1
85.9	87	90	92.3	92.1	91.2	75.2	79.4
83.1	87	88	94.6	94.8	82.2	90.1	84.7
83.9	87.2	89.3	94.1	95.1	82.7	91	84.8
83	87.4	87.1	94.9	94	82.3	91.2	85.3
77.6	76.4	70.3	68	84.2	64.2	45	63.8
77.1	75.8	71.2	67	85	64	47.4	64.2
78.2	75.4	71	67.2	84.8	63.5	46	63.4
63	72.7	77.6	82.2	70.8	67.1	57.1	60.5
64.1	72.2	78	82.5	70.4	68.2	57.5	61.3
63.4	72.9	78.2	83	71.5	67.4	58.1	60.6
87	96	91.8	85.2	82.6	77.5	70.8	86
88	97.2	91	85.7	81.8	77.6	71.4	87.1
88.2	96.3	92.1	86	82.1	78.1	71	86.5

Right Leg reach

- *With mean±SD:*

Ant	AntLat	Lat	PostLat	Post	PostMed	Med	AntMed
93.43333	90.56667	92.03333	95.83333	100.6	84.9	84	76.7
78.96667	83.2	90.66667	94.26667	108.5333	90.4	73.66667	71.86667

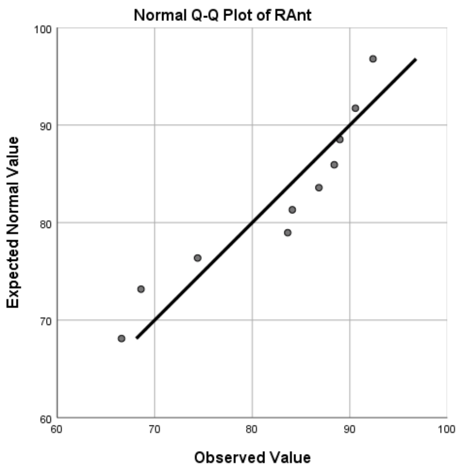
77.73333	82.03333	89.46667	99.4	104.3667	97.76667	82.56667	75.03333
74.03333	76.9	83.9	94.86667	91.66667	89.06667	65.83333	62.96667
80.83333	81.1	82.9	91.66667	92.16667	89.86667	72.96667	77.13333
81	82.76	87.79333	95.20667	99.46667	90.4	75.80667	72.74
85.96667	87.53333	89.6	91.96667	92.63333	91.76667	75.73333	79.66667
83.33333	87.2	88.13333	94.53333	94.63333	82.4	90.76667	84.93333
77.63333	75.86667	70.83333	67.4	84.66667	63.9	46.13333	63.8
63.5	72.6	77.93333	82.56667	70.9	67.56667	57.56667	60.8
87.73333	96.5	91.63333	85.63333	82.16667	77.73333	71.06667	86.53333
79.63333	83.94	83.62667	84.42	85	76.67333	68.25333	75.14667
6.615336	4.461958	3.708633	2.563453	6.670799	4.189352	6.716196	5.236767
8.772508	8.669625	7.968811	9.533604	8.472465	10.08361	15.33523	10.77997

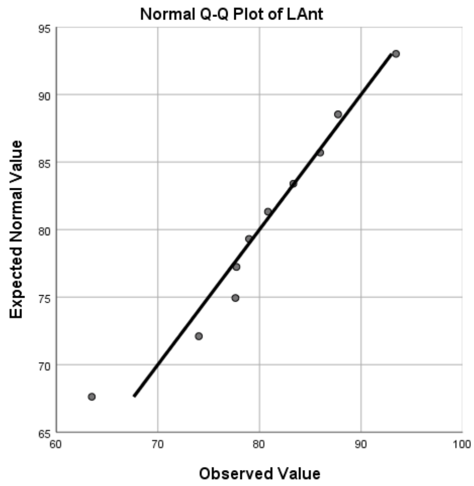
Right Leg reach

Appendix E: *Q-Q Plots for participants scores (**note**- prefixes "R" and "L" define right or left leg):*

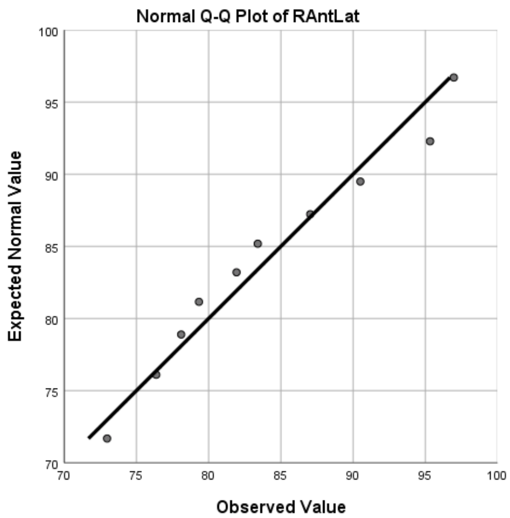
- ***SEBT:***

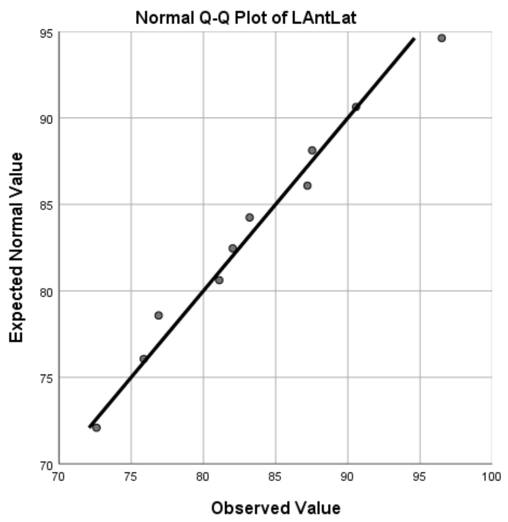
Anterior reach:



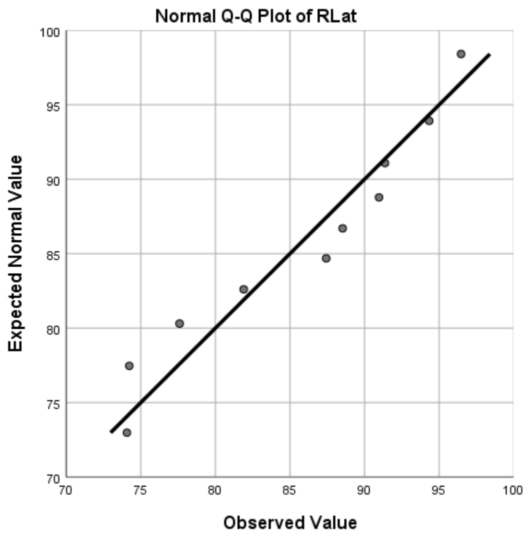


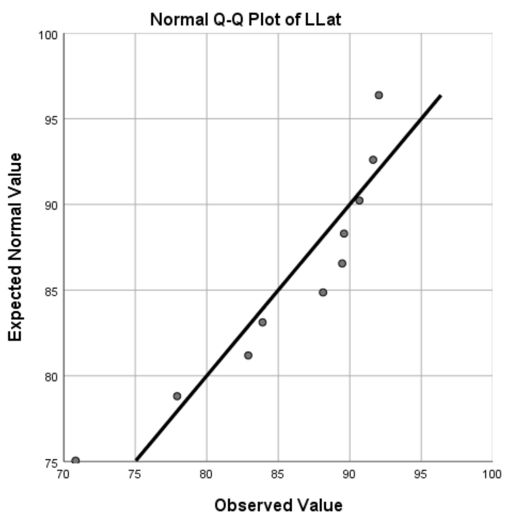
Anterolateral reach:



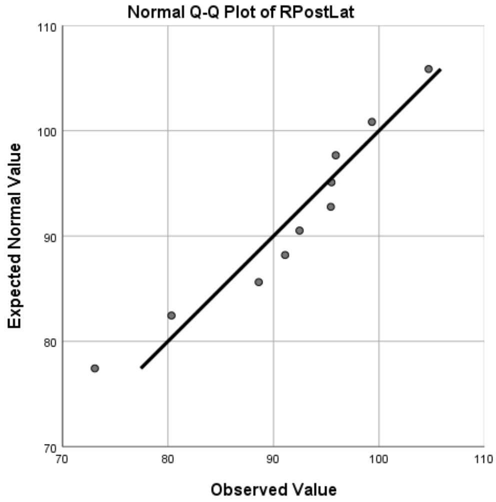


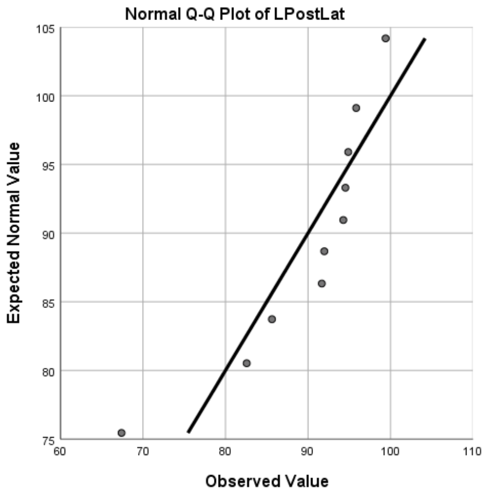
Lateral reach:



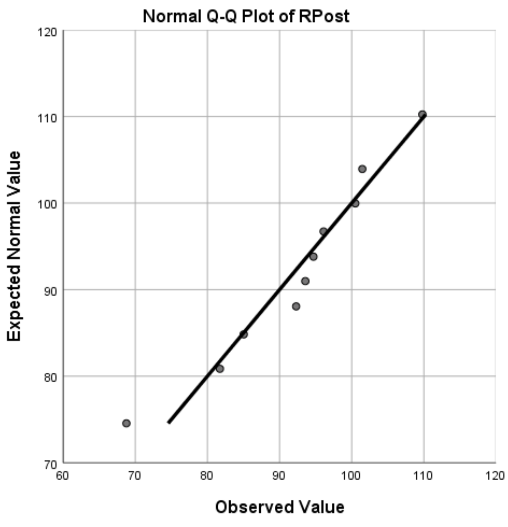


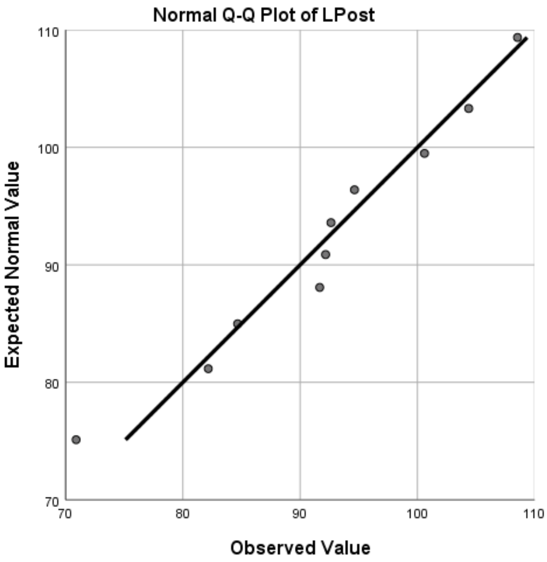
Posterolateral reach:



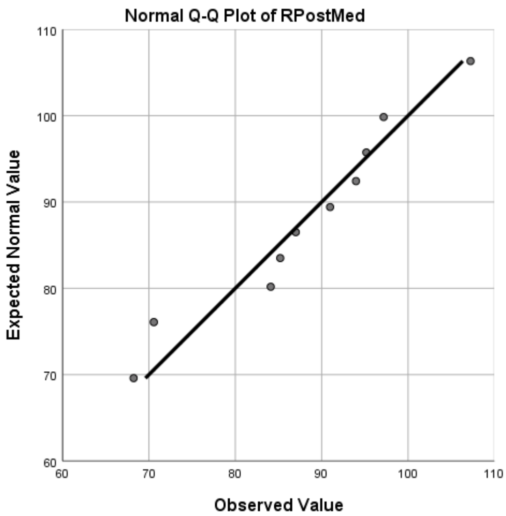


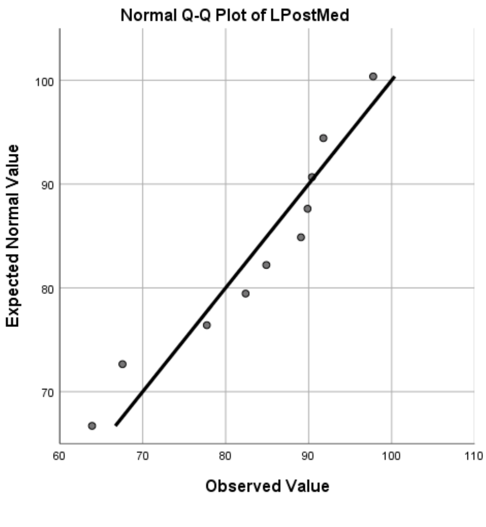
Posterior reach:



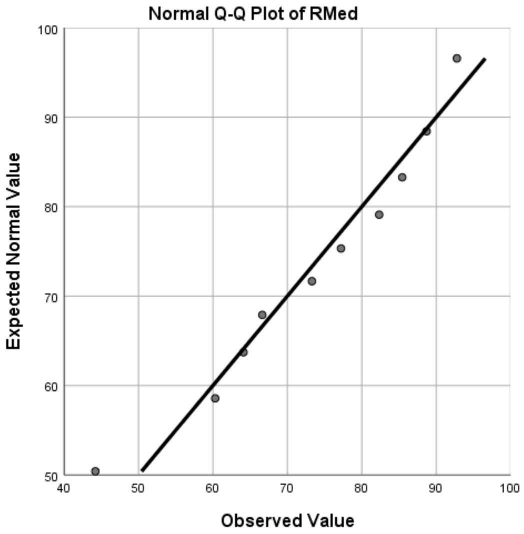


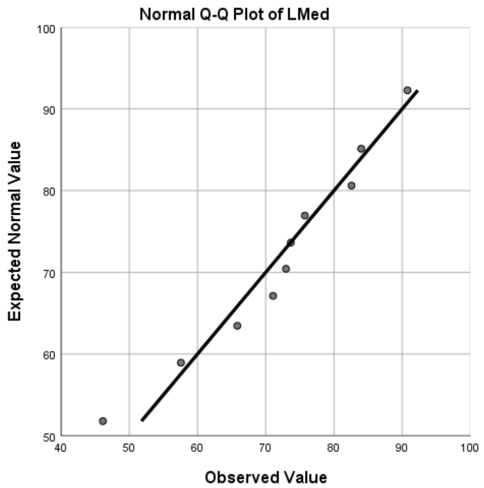
Posteromedial reach:



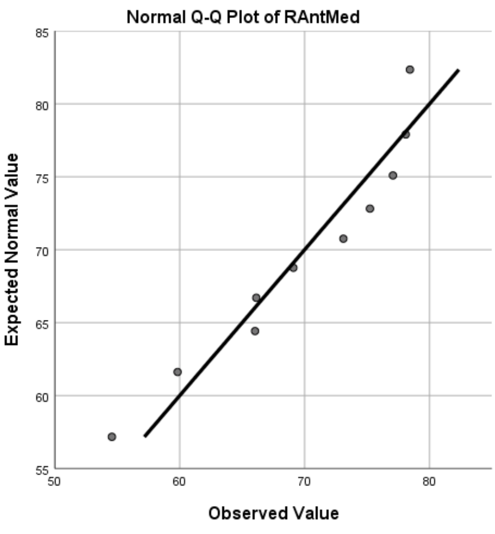


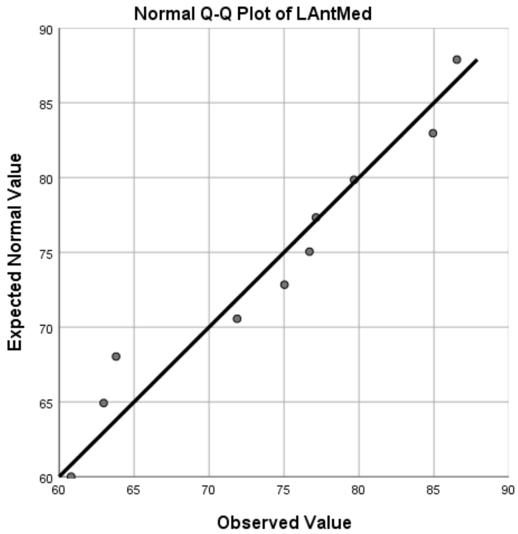
Medial reach:





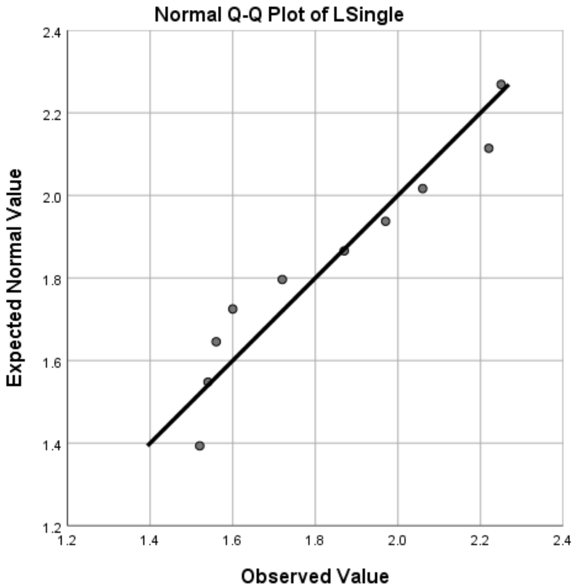
Anteromedial reach:



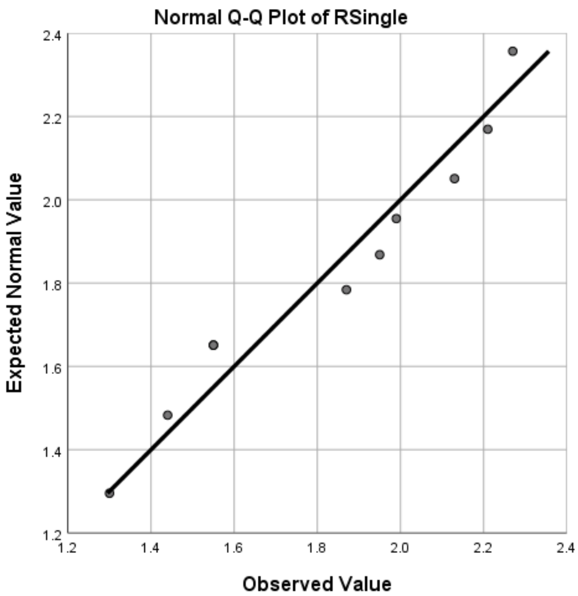

Normal Q-Q Plot of LAntMed
Expected Normal Value
Observed Value
90
85
80
75
70
65
60
60
65
70
75
80
85
90

HOP Tests:

Single:

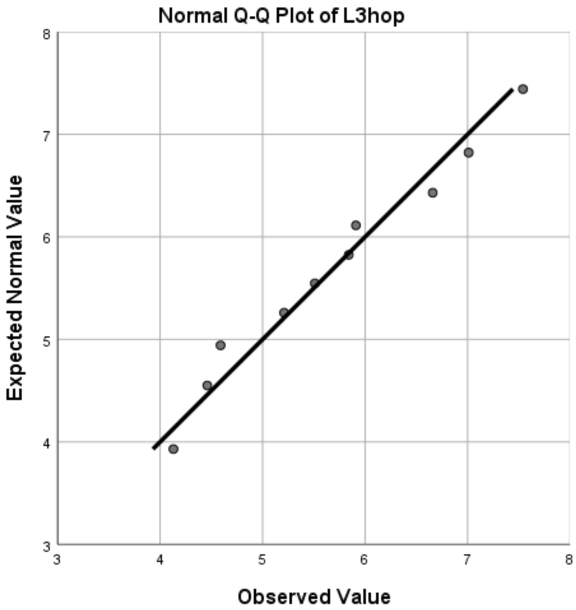


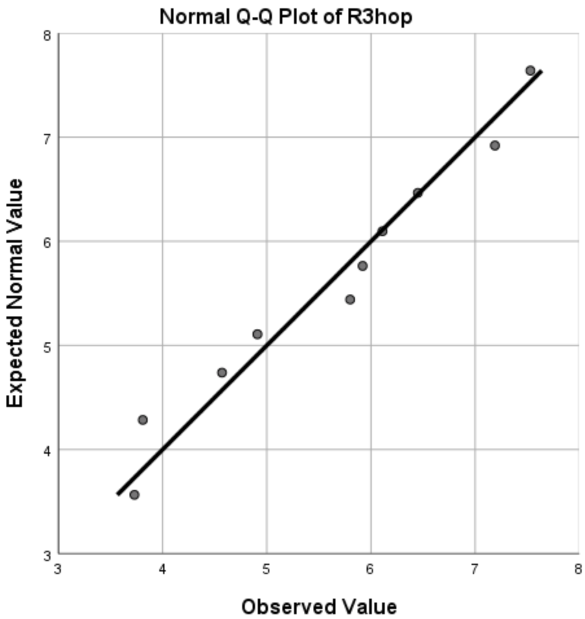
Normal Q-Q Plot of LSingle
Expected Normal Value
Observed Value
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.2
1.4
1.6
1.8
2.0
2.2
2.4



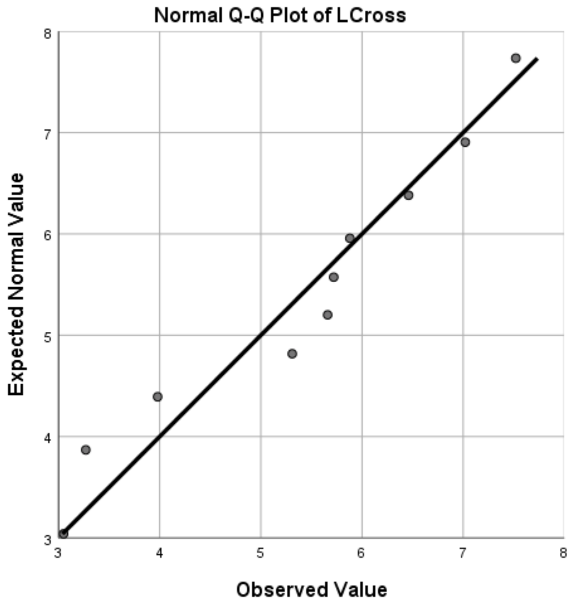
Normal Q-Q Plot of RSingle
Expected Normal Value
Observed Value
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.2
1.4
1.6
1.8
2.0
2.2
2.4

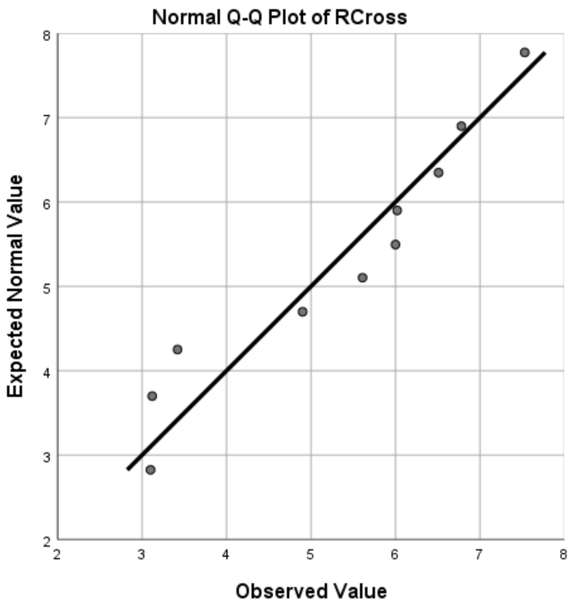
Three hop:


Normal Q-Q Plot of L3hop
Expected Normal Value
Observed Value
3
4
5
6
7
8

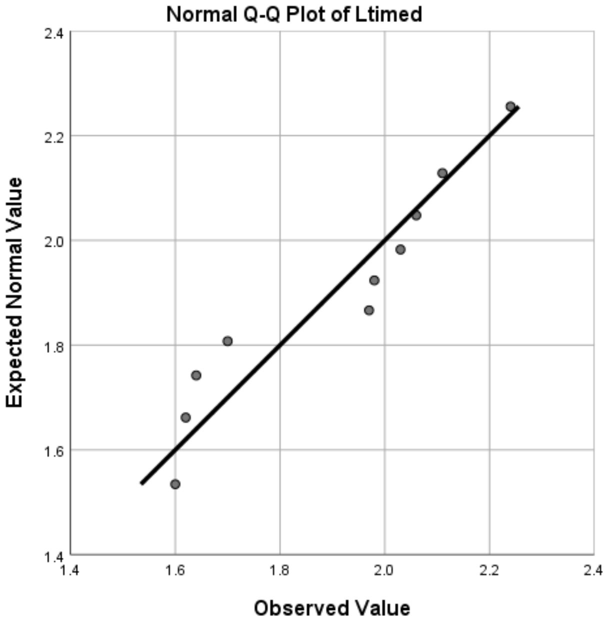

Normal Q-Q Plot of R3hop
Expected Normal Value
Observed Value
3
4
5
6
7
8

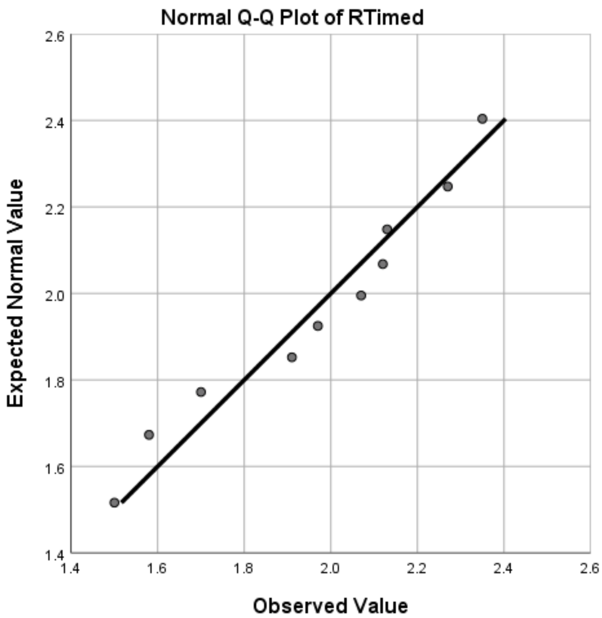
Crossover:


Normal Q-Q Plot of LCross
Expected Normal Value
Observed Value
3
4
5
6
7
8


Normal Q-Q Plot of RCross
Expected Normal Value
Observed Value
2
3
4
5
6
7
8

Timed:


Normal Q-Q Plot of Ltimed
Expected Normal Value
Observed Value
2.4
2.2
2.0
1.8
1.6
1.4
1.4
1.6
1.8
2.0
2.2
2.4


Normal Q-Q Plot of RTimed
Expected Normal Value
Observed Value
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.4
1.6
1.8
2.0
2.2
2.4
2.6

Appendix F: *SPSS Output for SEBT and HOP Tests*

- *Left leg SEBT output*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Anterior	Equal variances assumed	.484	.506	.249	8	.810	1.36600	5.48453	-11.28134	14.01334
	Equal variances not assumed			.249	7.436	.810	1.36600	5.48453	-11.45041	14.18241
AnteroLateral	Equal variances assumed	3.379	.103	-.242	8	.815	-1.18000	4.86728	-12.40396	10.04396
	Equal variances not assumed			-.242	5.971	.817	-1.18000	4.86728	-13.10370	10.74370
Lateral	Equal variances assumed	6.128	.038	.951	8	.369	4.17000	4.38383	-5.93913	14.27913
	Equal variances not assumed			.951	5.647	.380	4.17000	4.38383	-6.72133	15.06133
PosteroLateral	Equal variances assumed	3.477	.099	2.190	8	.060	10.78800	4.92571	-.57071	22.14671
	Equal variances not assumed			2.190	4.552	.085	10.78800	4.92571	-2.25794	23.83394
Posterior	Equal variances assumed	.094	.767	2.688	8	.028	14.46800	5.38230	2.05640	26.87960
	Equal variances not assumed			2.688	7.580	.029	14.46800	5.38230	1.93567	27.00033
PosteroMedial	Equal variances assumed	4.007	.080	2.518	8	.036	13.72800	5.45191	1.15588	26.30012
	Equal variances not assumed			2.518	5.326	.050	13.72800	5.45191	-.03254	27.48854
Medial	Equal variances assumed	2.838	.131	.903	8	.393	7.55400	8.36489	-11.73548	26.84348
	Equal variances not assumed			.903	5.479	.404	7.55400	8.36489	-13.39582	28.50382
AnteroMedial	Equal variances assumed	7.390	.026	-.402	8	.698	-2.40600	5.98638	-16.21062	11.39862
	Equal variances not assumed			-.402	5.782	.702	-2.40600	5.98638	-17.18910	12.37710

- *Right leg SEBT output*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Anterior	Equal variances assumed	.018	.897	-.537	8	.606	-3.28200	6.10930	-17.37008	10.80608
	Equal variances not assumed			-.537	7.892	.606	-3.28200	6.10930	-17.40363	10.83963
AnteroLateral	Equal variances assumed	5.038	.055	-1.328	8	.221	-6.52200	4.91146	-17.84784	4.80384
	Equal variances not assumed			-1.328	6.178	.231	-6.52200	4.91146	-18.45639	5.41239
Lateral	Equal variances assumed	8.944	.017	-.118	8	.909	-.64800	5.51004	-13.35417	12.05817
	Equal variances not assumed			-.118	5.903	.910	-.64800	5.51004	-14.18453	12.88853
PosteroLateral	Equal variances assumed	5.141	.053	1.123	8	.294	6.43400	5.72976	-6.77885	19.64685
	Equal variances not assumed			1.123	4.535	.317	6.43400	5.72976	-8.76102	21.62902
Posterior	Equal variances assumed	1.328	.282	1.880	8	.097	12.11400	6.44463	-2.74733	26.97533
	Equal variances not assumed			1.880	6.307	.107	12.11400	6.44463	-3.47096	27.69896
PosteroMedial	Equal variances assumed	1.880	.208	1.257	8	.244	9.14600	7.27778	-7.63659	25.92859
	Equal variances not assumed			1.257	7.177	.248	9.14600	7.27778	-7.97761	26.26961
Medial	Equal variances assumed	1.077	.330	1.489	8	.175	13.19200	8.85893	-7.23672	33.62072
	Equal variances not assumed			1.489	6.589	.183	13.19200	8.85893	-8.02403	34.40803
AnteroMedial	Equal variances assumed	.469	.513	.013	8	.990	.07000	5.45936	-12.51930	12.65930
	Equal variances not assumed			.013	7.462	.990	.07000	5.45936	-12.67897	12.81897

- *Left leg HOP Tests output*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Single	Equal variances assumed	.138	.720	5.053	8	.001	.56800	.11240	.30880	.82720
	Equal variances not assumed			5.053	6.904	.002	.56800	.11240	.30146	.83454
ThreeHop	Equal variances assumed	.060	.812	4.219	8	.003	2.07600	.49201	.94142	3.21058
	Equal variances not assumed			4.219	7.684	.003	2.07600	.49201	.93325	3.21875
Crossover	Equal variances assumed	5.156	.053	4.316	8	.003	2.53800	.58801	1.18205	3.89395
	Equal variances not assumed			4.316	6.203	.005	2.53800	.58801	1.11054	3.96546
Timed	Equal variances assumed	.049	.831	-1.117	8	.296	-.20000	.17903	-.61283	.21283
	Equal variances not assumed			-1.117	7.802	.297	-.20000	.17903	-.61467	.21467

- *Right leg HOP Tests output*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Single	Equal variances assumed	3.306	.107	6.023	8	.000	.48600	.08068	.29994	.67206
	Equal variances not assumed			6.023	5.822	.001	.48600	.08068	.28710	.68490
ThreeHop	Equal variances assumed	.361	.565	4.403	8	.002	1.81200	.41155	.86296	2.76104
	Equal variances not assumed			4.403	7.547	.003	1.81200	.41155	.85296	2.77104
Crossover	Equal variances assumed	2.390	.161	3.608	8	.007	2.26600	.62802	.81779	3.71421
	Equal variances not assumed			3.608	6.820	.009	2.26600	.62802	.77298	3.75902
Timed	Equal variances assumed	.121	.737	.090	8	.931	.01400	.15633	-.34649	.37449
	Equal variances not assumed			.090	8.000	.931	.01400	.15633	-.34649	.37449