University of New South Wales

# BIOM9541 Major Assignment



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# Contents



# List of Figures



# List of Tables

**Abstract**

The utilisation of backwards walking has recently emerged as an alternative for an exercise methodology. For that reason, many studies were published to enhance knowledge in the field. This present study replicated the study of Kinematics and Kinetic Analysis during Forward and Backward Walking[1] to understand the mechanism of gait in backward walking by comparing it to forward walking. A three-dimensional motion capture system was used to gain the joint characteristics and to calculate the joint moments and the powers during walking. Ground reaction force curves were obtained from force plates. Each participant performed five Forward Walking (FW) and Backward Walking (BW) trials with bare feet. All data were analyzed using paired t-tests to discover the significant differences between FW and BW. This study presented that stride characteristics in FW and BW were significantly different. Joint angles in the ankle, knee and hip indicated similar patterns in FW and BW although it showed different value in specific characteristics. The characteristics of ankle joint moment were slightly similar in FW and time-reversed BW but it was dissimilar in the knee and hip joint. The joint powers characteristics in all joint between FW and BW varied greatly. The ground reaction force (GRF) during FW and BW showed similar patterns. Despite the discrepancies and poor reliability within the backwards walking scenarios, there was a clear correlation between the kinetics and kinematics during forwards and backwards walking as clarified via the reference paper.

# 1 Introduction

The utilisation of Backward walking exists as an alternative for an exercise methodology that enables the enhancement of balance and muscle strength of the lower limbs, improving balance in medial-lateral and anterior-posterior balance[2] as well as the approach of utilising backwards walking as a rehabilitation method on improving upright mobility, backward gait speed and self-confidence in balance [3].

Studies have shown that the movement between leg trajectories in forward and backward motion are essentially mirrored, albeit, movements occur in the reversed direction. It has been reviewed that angular displacements at the hip,knee and ankle joints show similar overall magnitudes and patterns in both walking trends [4]. However, the phase-dependent modulation of medium-latency responses recorded in other studies have shown that in backwards walking, the modulation pattern was different from the one seen during forward walking. The responses correlated to the responses in the semitendinosus, biceps femoris, rectus femoris and the tibialis anterior [5]. Further research suggested results that through the implementation of backward walking, additional muscular demands which are requested from the participants; muscle stimulation enables a platform for adapting a rehabilitation program for building of strength through knee and ankle support, however, the process was only conducted through an electromyographic and kinematic analysis [6]. This suggests that the lack of search on backward and forward walking lies prominently in the kinetic analysis.

This report aims to replicate the Kinematics and Kinetic Analysis during forward and backward walking, finding strong results and correlation via the motion analysis in backwards walking in comparison to forward walking. Furthermore, the present study also aims to focused on the spatiotemporal parameters and the similarities of Backward Walking kinematics and kinetics to those of the normal Forward-Walking, with the results and discussion contribution further to the mechanism of gait in Backwards Walking [1].

# 2 Literature Review

## 2.1 Therapeutic Effects

Balance has been defined as the ability for one to maintain equilibrium, while the center of gravity shifts in the process of a certain action. Specifically, dynamic balance and its close association to walking showcases the importance of one's ability to respond appropriately to their changing physical environment and tasks. Studies have been aimed to discuss the effects of forward and backwards walking on gait and balance ability. It has been shown that backwards walking enables significant increments in both the medial-lateral and anterior-posterior balance, as well as improve step length and velocity. Furthermore, forward walking similarly provides improvements in medial-lateral and anterior-posterior balance [2] . Additionally, based on a study regarding chronic incomplete spinal injury, the results obtained from the research concludes that improved balance was evident, and upright mobility improved as well. Furthermore, there was a positive correlation to the backward gait speed, as well as providing a strong improvement in self-reported balance confidence. This further emphasis the therapeutic effects of Backwards walking, and its fundamental benefits as a means to a rehabilitation approach [3] .

## 2.2 Forward Walking a Reversal of Backward Walking

Another key exploration in the area of lower limb motion is the comparison between the functionality of forward walking to backward walking. More specifically, the equality between forward walking and a time-reversed backward walking. Through the article "Backward Walking: a simple reversal of forward walking?" it has been determined that joint angle patterns with the reversed time-based backward walking were similar, however an exception exists for the ankle. Moment patterns across the joints were similar except for the knee, but joint muscle power were almost a reversed-polarity images of each other. The results concluded from the study suggests concentric muscle activity in forward walking would become the eccentric activity of the backward walking, and vice-versa [7].

# 3 Methodology

## 3.1 Participants

A clinical trial was established where two participants, 1 male and 1 female, were selected to undergo a series of forwards and backwards walking trials. The male participant was aged 23 years old, weighed approx. 76kgs and was 172cm tall. The female participant was aged 21 years old, weighed approx. 54.1kgs and was 159cm tall. The participants were given information about the tasks prior to the trial and given consent forms to sign before being allowed to proceed with the experiment.

## 3.2 Experimental Instrumentation

The subjects were asked to change to form fitting clothing before being fitted with 16 reflective markers (14mm in diameter) using double-sided non-reflective tape. Along the walls and roof were 8 high definition infrared cameras capable of detecting the markers and capturing infrared wavelength data at around 120Hz. Along the designated walkway, located under the carpet were a pair of Kistler force plates used to capture the force of the participants foot as they hit the floor. The data was sent to a three-dimensional motion capture software known as VICON Nexus 1.8 which was used to process the joint movements and force-plate data as a function of time and spatial location. Prior to the trials, a calibration test was conducted with 8 reflective markers attached to a "wand" which was waved around the room in a series of curves and arcs in order to allow the software to generate a series of sampling datasets.

## 3.3 Experimental Procedure

During the set-up phase of the trial, the participants had various anthropometric measurements taken of their lower-extremities as well as supplementary information such as their age, height and weight. Each participant performed a series of trials until a set of five "good" trials could be obtained for forwards and backwards walking. In this experiment, a "good" trial was defined as a walking trial where the markers would be visible for the majority of the capture walkway and would require little to no post-processing, each trial was checked immediately afterwards to confirm if it was successful or not. Participants were given a few trial runs to practise walking across the designated walkway before the trials began to allow them to adjust to their natural walking cadence and stride length.

## 3.4 Data Analysis

Post-trial, each data set was analysed using the aforementioned VICON software to correct any experimental errors such as missing markers using the pre-programmed correction code. The data collected was cut such that one full gait cycle was shown, from initial contact to initial contact, with the remaining data cut from the recorded dataset to reduce file size.

Once processed, the data was assessed using Mokka analysis software which provided a CSV exportation of the c3d files produced by VICON. Due to the vast amount of raw data that was exported into CSV, a custom python script was used to calculate all the Gait, Kinematics and Kinetics characteristics, producing mean output for all the participants data in .txt format. To ensure the script would not encounter runtime errors, all of the CSV files were edited to follow a particular format (appendix for more info about this).

A number of simulations for both Forward and Backward walking trials for the male and female participants were generated using the Inverse Kinematics tool provided by OpenSim 3.3. The backwards walking trials were time-reversed and plotted as a function of inverse time to accurately fit the data with the forwards walking trials to test our hypothesis, that a backwards walking trial with time inversion would generate similar gait cycle profiles to forwards walking. Each gait cycle was normalised to a time-frame between 0% and 100% of a complete gait cycle, this would allow for any major or minor variations within each trial to be considered and factored into the final plot.

### 3.4.1 Ground Reaction Force

Each trial was given as a weight, diving by gravity we were able to separate the weight to the force. The force was divided by the body weight of the participants and then converted to a percentage.

# 4 Results

## 4.1 Stride Characteristics

Table 1 presents the change in stride characteristics value for BW compared with FW as the baseline. Walking speed and cadence decrease significantly while stride length only shows a slight decrease from 1.03 ∓0.05 m/s to 1.03 ∓0.05 m/s ($p<0.002$), 101.34∓2.35 steps/min to 60.03 ∓11.34 steps/min ($p<0.002$) and 1.19 ∓0.05 m to 1.05 ∓0.04 m ($p<0.02$) respectively during BW. Meanwhile, stance phase and stride time in BW compared to FW increase significantly from 59.34 ∓1.34 % to 65.34 ∓5.34% ($p=0.2$) and 1.18 ∓0.01s to 2.88 ∓0.56s ($p<0.001$).

| **Stride Characteristics** | **Forward Walking (FW)** MEAN ∓ SD | **Backward Walking (BW)** MEAN ∓ SD | **P-Value** |
|---|---|---|---|
| **Walking Speed (m/s)** | 1.03 ∓ 0.05 | 0.53 ∓ 0.03 | < 0.002 ** |
| **Cadence Speed (steps/min)** | 101.34 ∓ 2.35 | 60.03 ∓ 11.34 | <0.002 ** |
| **Stance Phase Percentange in Gait Cycle (%)** | 59.34 ∓ 1.34 | 65.34 ∓ 5.34 | 0.2 |
| **Stride Time (s)** | 1.18 ∓ 0.01 | 2.88 ∓ 0.56 | <0.001 ** |
| **Stride Length (m)** | 1.19 ∓ 0.05 | 1.05 ∓ 0.04 | 0.02 |

*p < 0.05; **p < 0.01

Table 1: Stride Characteristics: Forward Walking vs Backward Walking Averaged Over All Participants

## 4.2 Kinematics

Joint angles in the ankle, knee and hip indicate similar pattern in FW and BW as seen from Fig.1. However, there are discrepancies in analyzed variables for three stated joints between FW and BW (Table 2). The ankle joint incurred more plantarfexion at pre-swing in BW ($p=0.2$) and during swing phase in FW ($p=0.05$) than at loading response in FW and during swing phase in BW. While in the stance phase, it was less dorsiflexed in BW than in FW ($p=0.1$). The total range of motion in FW is greater than in BW for the ankle joint ($p=0.07$).

The knee showed higher flexion angle at pre-swing in BW than at loading response in FW ($p<0.001$) and less flexed during swing phase in BW than in FW ($p<0.001$). The total range of motion of the knee was also greater in FW than in BW ($p<0.001$).

The hip showed significantly less flexed at heel strike during FW then at heel off during BW ($p<0.001$) and less extended at stance phase of BW than that in FW ($p<0.001$). The total range of hip motion was greater in FW ($p<0.001$).

## 4.3 Kinetics

### 4.3.1 Joint Moments

The characteristics of ankle joint moment were slightly similar in FW and time-reversed BW. However, the knee and hip joint moment in time-reversed BW showed dissimilar characteristics with FW (Fig. 1b and c). The maximum dorsiflexor moment of ankle was smaller in FW than in BW ($p=0.02$) while the maximum plantarflexor moment was larger in FW than in BW ($p=0.114$).

There was a slight decrease in maximum extensor moment of knee in BW from that in FW ($p<0.001$). On the other hand, the maximum flexor moment of knee in stance phase during BW decreased considerably from FW ($p<0.001$). The hip showed significantly larger value of the maximum extensor moment in stance phase during FW than in BW ($p<0.001$). The maximum flexor moment of hip in stance in FW was larger than in BW ($p<0.001$).

### 4.3.2 Joint Powers

Figure 1 and 2 shows that the joint powers characteristics between FW and BW were different. The maximum power generation of ankle joint (Table 2) during FW were significantly larger than BW ($p<0.001$). Accordingly, its maximum power absorption became larger during BW than FW ($p<0.001$). In the knee joint, the maximum power generation and absorption in loading response during FW were larger than during BW ($p<0.001$). The difference of the maximum power generation were smaller than the maximum power absorption between FW and BW. In the loading phase, the maximum power generation of hip joint were slightly larger during FW than BW ($p<0.001$). While in the swing phase, the maximum power generation were significantly larger during FW than BW ($p<0.001$).

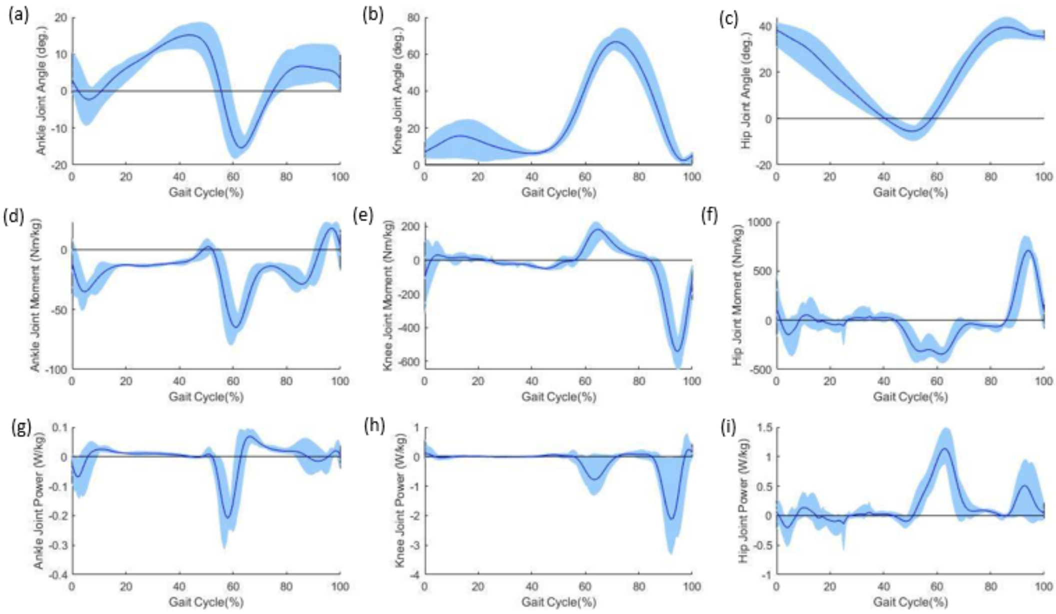


Figure 1: Mean joint angles (a) Ankle joint, (b) Knee joint, and (c) Hip joint. Mean moments (d) Ankle joint, (e) Knee joint and (f) Hip joint. Joint power of (g) Ankle joint, (h) Knee joint and (i) Hip joint, of Forward Walking

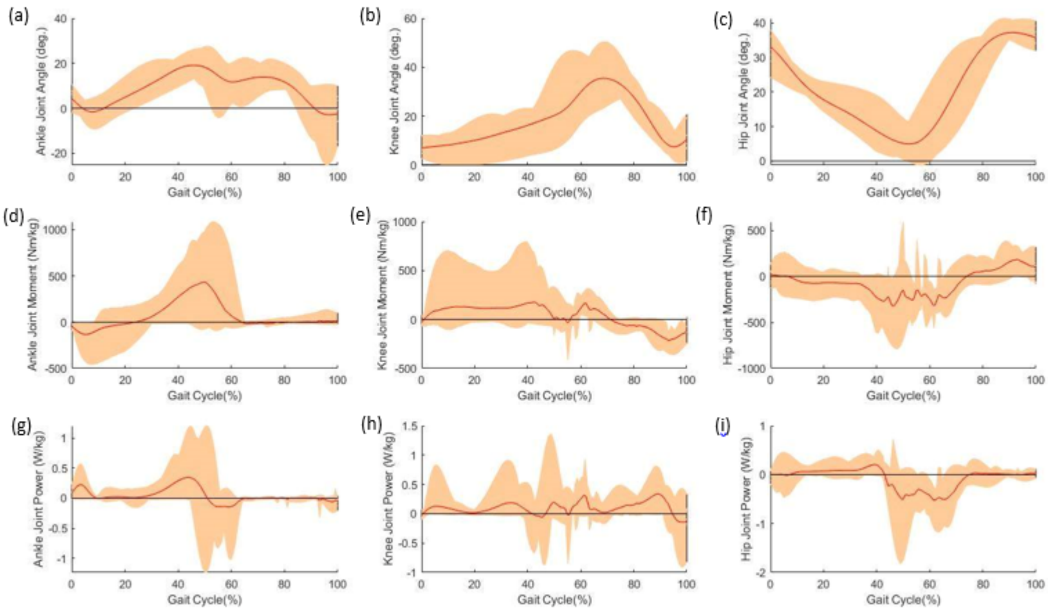


Figure 2: Mean joint angles (a) Ankle joint, (b) Knee joint, and (c) Hip joint. Mean moments (d) Ankle joint, (e) Knee joint and (f) Hip joint. Joint power of (g) Ankle joint, (h) Knee joint and (i) Hip joint, for time reversed Backwards Walking

| Kinematics Characteristics | Forward Walking (FW) MEAN ∓ SD | Backward Walking (BW) MEAN ∓ SD | P-Value |
|---|---|---|---|
| **Ankle Variable** | - | - | - |
| **Max Plantarflexion in Loading Response Pre-Swing in BW** | -14 ∓ 1.3 | -16 ∓ 2.7 | 0.2 |
| **Max Dorsiflexion in Stance** | 7 ∓ 1.4 | -1 ∓ 2 | <0.001** |
| **Max Plantarflexion in Swing** | -13 ∓ 3.4 | -12 ∓ 2.6 | <0.001** |
| **Total Range in Motion** | 20 ∓ 3.6 | 11 ∓ 2.8 | <0.001** |
| **Max Dorsiflexor Moment** | -0.017 ∓ 0.04 | -0.015 ∓ 0.02 | 0.02 |
| **Max Plantarflexor Moment (Nm/kg)** | 0.78 ∓ 0.03 | 0.67 ∓ 0.2 | 0.114 |
| **Max Power Generation (W/kg)** | 3.21 ∓0.2 | 1.25 ∓ 0.11 | <0.001** |
| **Max Power Absorption (W/kg)** | 0.4 ∓ 0.3 | -3.4 ∓ 0.3 | <0.001** |
| **Knee Variable** | - | - | - |
| **Max flexion in Loading Response Pre-Swing in BW** | 22 ∓ 2.4 | 31 ∓ 4.3 | <0.001** |
| **Max flexion in Swing (8)** | 62 ∓ 3.1 | 43 ∓ 7.6 | <0.001** |
| **Total Range of Motion (8)** | 64 ∓ 4.5 | 45 ∓ 7.2 | <0.001** |
| **Max Extensor Moment (Nm/kg)** | 0.47 ∓ 0.04 | 0.41 ∓ 0.12 | <0.001** |
| **Max flexor Moment in Stance (Nm/kg)** | -0.24∓ 0.11 | 0.01 ∓ 0.03 | 0.001** |
| **Max Power Generation (W/kg)** | 0.99 ∓ 0.45 | 0.80 ∓ 0.22 | <0.001** |
| **Max Power Absorption in Loading Response (W/kg)** | -0.79 ∓ 0.34 | -0.15 ∓ 0.13 | <0.001** |
| **Hip Variable** | - | - | - |
| **Flexion at Heel Strike (Heel off in BW (8))** | 39 ∓ 3.2 | 39 ∓ 3.2 | <0.001** |
| **Max extension in Stance (8)** | -7 ∓ 3.1 | 2.3 ∓ 4.3 | <0.001** |
| **Total Range of Motion (8)** | 45 ∓ 3.5 | 11.3 ∓ 4.5 | <0.001** |
| **Max Extensor Moment (Nm/kg)** | 0.5 ∓ 0.12 | 0.05 ∓ 0.09 | <0.001** |
| **Max flexor Moment in Stance (Nm/kg)** | -0.6 ∓ 0.2 | -0.45 ∓ 0.12 | 0.001** |
| **Max Power Generation in Loading Response (W/kg)** | 0.6 ∓ 0.14 | 0.54 ∓ 0.21 | <0.001** |
| **Max Power Generation in Swing (W/kg)** | 1.24 ∓ 0.19 | 0.11 ∓ 0.03 | <0.001** |

$^*p < 0.05$; $^{**}p < 0.01$

Table 2: Comparison of joint angles and moments variables: forward walking vs. backward walking

#### 4.3.3 Ground Reaction Force

The GRF curves (Fig.3 and Fig.4) during FW and BW showed slightly similar patterns with two different main peaks in the loading response and pre-swing phase. During FW, the GRF in the loading response that was the first peak of the curve was smaller than that during BW. Meanwhile in the pre-swing phase, the GRF during FW was larger than during BW.

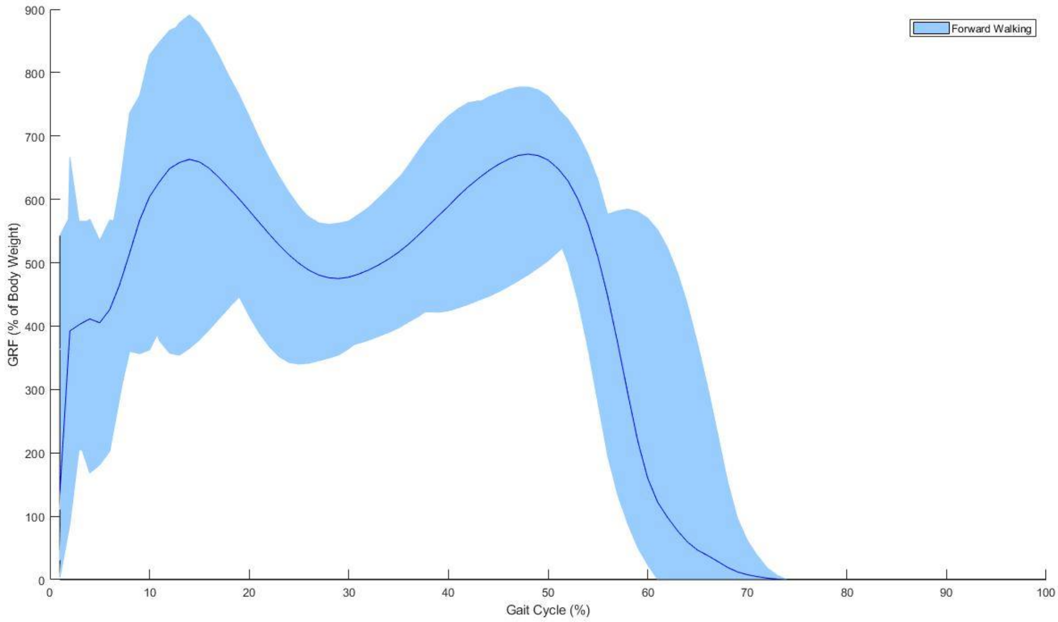


Figure 3: GRF curves during Forward Walking Averaged Over All Participants

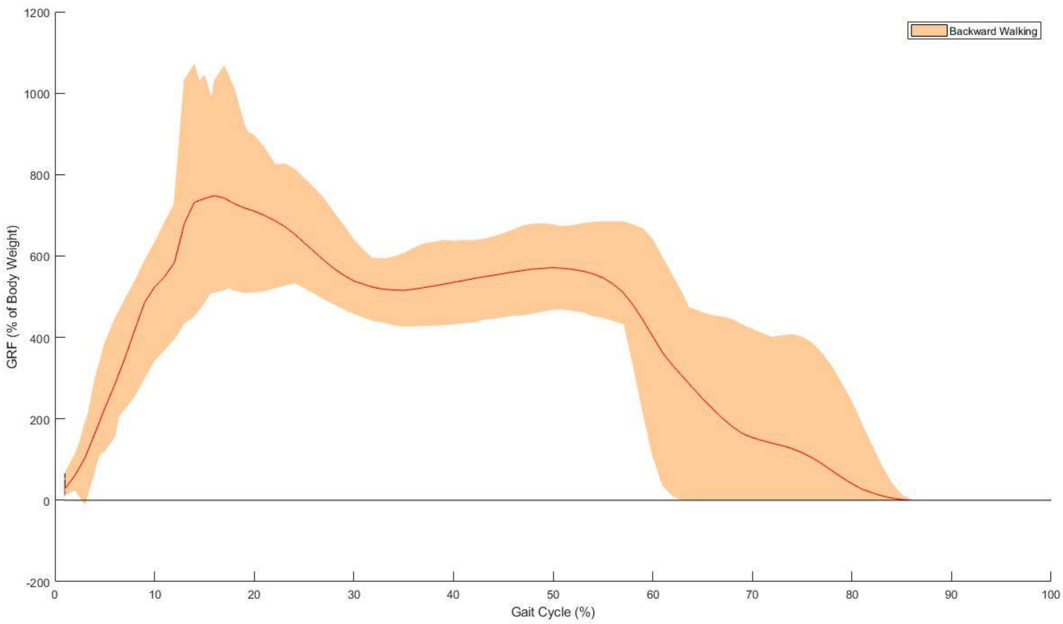


Figure 4: GRF curves during Backwards Walking Averaged Over All Participants

# 5 Discussion

## 5.1 Overview and Trends

Forward walking data shows good reliability, results are repeatable and clustered. Similar results obtained in relevant paper for FW trials.

When the forward walking trials are considered alone we can very evidently see that the results are significantly more clustered and follow similar trends. A comparison of the data obtained with those of our reference paper indicate very similar results for the joint angles, moments and power for all of the primary joints in the lower extremities [1]. Slight variations can be seen in the general trend of the data plots, however this can simply be attributed to the differences in the sample sizes of the datasets analysed. In the reference article, 310 forwards walking trials were analysed and averaged to generate a normalised mean distribution profile, our trials involved only 2 participants and a total of 8 trials which is under the sample size required for an accurate mean distribution of data, thus inconsistencies can arise due to sampling size error.

A direct comparison of backwards walking data shows greater inconsistencies when compared to our reference article[1] where the reference article conducted 1240 trials for backwards walking over a sample size of 31 participants [1].

Backwards walking data has poor reliability, random noise evident in the data. General trend is the same but the repeatability of results is probably poor. Backwards walking is not natural, likely reason for the unnatural gait.

## 5.2 Gait Characteristics

The variability of data between Forward and Backward walking is evident when considering the Gait parameters [8]. Due to the unnatural movement of walking backwards, the walking speed of the trials was considerably less than forward walking. This could be a result of the participant exhibiting caution whilst moving in this unnatural fashion [9]. Consequently, all the other characteristics were affected to the same extent, resulting in longer duration to finish the trials and lower cadence values. Interestingly, the Stance Phase percentage for the Backward walking was also higher than forward as the participants would hesitate while the other leg was in the swing stance.

Comparing these results with the reference paper, we can establish that forward walking trials produce nearly identical Gait results despite the various ways an individual may walk [1]. However, backward walking can produce highly variable results as there is no set way as to how an individual should walk backwards in terms of speed, muscle movement or whether, or not, an individual should look in the direction of motion [8][10].

## 5.3 Kinematics and Kinetics

The kinematic parameters for the ankle variables showed higher variability compared with the knee and hip for both forward and backward walking. The joint ankles in the angle showed the highest variability among all of the characteristics. This is evident, as the un-orthodox method of walking backwards suggests that same participant walked differently in terms of how to place their place their ankle, how much should they extend the plantar-flexors and adjust to toe strike-heel lift phase [8]. In comparison to the reference paper, the other kinematic parameters (knee and hip) are quite similar.

During backwards walking, we observe that the power absorption was much lower than in forward walking indicating that the knee and ankle joint plays a significant role in absorbing shocks during movement. This result indicated that the shock absorption at foot strike in the knee joint was reduced during BW, because of the greater shock absorption in the ankle joint. An evident result of the simpler pattern of knee joint displacement during BW, the power output was decreased significantly [1].

The ankle joint also generated the most power out of all the joints as this joint plays an important role in moving the trunk backwards during BW. The other joints experienced lower power generations despite other studies showing that the hip and knee extensors play a vital role in the thrust of the body during BW [11].

The muscle joint moments in both the knee and the hip were also similar to the values in the reference paper, with the Knee joint moment showing the most variability in data, this makes sense because the knee incurs the most variability during walking.

An interesting observation in the results is the large and significantly various total range of motions for the joint angles during both walking motions.This could be a result of the nature of the both the participants' walking as well as the balance lab, where the experiment was conducted, was a controlled environment. Despite a "Controlled Environment" being ideal for such studies, the psychological effect of being wary to not perform poorly as a subject may be a reason in higher range of motions for the joints [9].

The GRF in both forward and backward walking are similar when BW is time reversed as a function [1][11]. The first peak shows that in BW the GRF would be generally higher as the toe strike and the maximal extension of the ankle plantarflexors produced more force compared to FW heel strike as well as the BW heel lift. While the second peak, the FW toe lift produces a higher force value than the BW heel lift as the hip joints were merely lifting the limb and moving it backward.

Additionally, the re-calibration of the test environment may have played a role in affecting the results for all the parameters. The trials before the re calibration seemed to be producing erroneous results and lead the experimental team to take the decision and re calibrate the environment. Due to time and resources being constrained, the previous trails before this process were also considered in the final analysis of the results and may have played a part in the high variability of the results.

# 6 Conclusion

Despite the discrepancies and poor reliability within the backwards walking scenarios, we conclusively determined that there is a clear correlation between the kinetics and kinematics during forwards and backwards walking. This is particularly evident in the forward walking cases where the gait characteristics and cadence were highly comparable to the reference articles. However, backwards walking data suggested a highly volatile distribution of gait, cadence and power output with sporadic results emphasising the difficulty of walking in an unnatural manner such as backwards. Disparities in power outputs within backwards walking also suggested that absorption though the joints may have deviated due to psychological factors of the participants performance in the experiment, but clearly indicates a clear relationship to the reference papers and our expected results.

Improvements to this experiment can be made through an increased sample size by utilising more participants to record data and repeating with each individual multiple times to generate a more normally distributed result. Furthermore, marker placement on the body can be more accurately positioned and by using clothing which does not obstruct the line of sight of the camera's would be beneficial to data collection. Also, recalibration of the infrared cameras interspersed between the trials would aid accuracy and giving time for them to cool down between trials may prevent them from deviating the data prematurely. Overall, we successfully determined the correspondence between forwards and backwards walking with regards to their individual kinetics and kinematics and the overall spatiotemporal parameters which inevitably define their unique characteristics.

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