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Examining the effects of combined gait retraining and video self-modeling on habitual runners experiencing knee pain: A pilot study

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Running Head: GAIT RETRAINING AND VIDEO SELF-MODELING

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This multidisciplinary study aimed to reduce stride length (SL) by 2-4% for two runners (P1, P2) experiencing chronic knee pain using a biomechanical gait retraining and video self-modeling intervention. The pre – post-test design examined the acute changes in biomechanical and psychological factors following a four-week intervention, which involved four gait retraining sessions and four gait consolidation sessions. Participants watched self-modeling videos twice daily in between sessions. P1 met the required SL reduction (2.61%), resulting in a 9% decrease in peak vertical ground reaction force combined with a 72% reduction in peak knee abduction moment. P1 demonstrated large positive effects for four performance- and two injury-based psychological variables (*ES* = 0.85-4.30) and a large negative effect for one injury-based psychological variable (*ES* = 1.50). P2 did not meet the required reduction in SL (1.3%), the response was an increase in vertical ground reaction forces (0.90%). P2 demonstrated large positive effects for three performance- and two injury-based psychological variables (*ES* = 3.00-4.28) and a large negative for one performance-based psychological variable (*ES* = 3.65). The consideration for individualised responses to interventions targeting a change in gait are warranted, as applying a ‘one-size-fits-all’ approach may be detrimental to reducing injury pain.

Keywords: Patellofemoral pain, multi-disciplinary intervention, motor learning, applied sport science

1 INTRODUCTION

The popularity of recreational running has increased dramatically over the last few decades, with a survey in 2014 suggesting 36% of adult Europeans participate in running training[1]. Approximately 75% of runners sustain at least one injury per year, with patellofemoral pain the most common[2]. Increasing popularity and injury rates associated with running are leading to greater medical demands and emphasise the need for evidence-informed rehabilitation strategies.

Peak vertical ground reaction forces (GRF) and the vertical rate of force are strong predictors of injury risk and are involved in several injury aetiologies, including patellofemoral pain[3] and anterior knee pain[4].The link between loading measures and injury risk has resulted in recent research assessing runners' responses to gait retraining, which aims to reduce loading in the lower limbs[5]. Step length (SL) and step frequency (SF) are popular variables targeted for gait manipulation, where a 10% increase in SF can initiate a 2.6% reduction in peak vertical GRF, a 5.5% reduction in peak horizontal GRF and a strong relationship between vertical GRF and patellofemoral force is observed[6]. Willy and colleagues[5] found that a 7.5% increase in SF caused a 17.9% reduction in the vertical rate of force and a 26.9% reduction in negative work at the knee joint. A significant reduction in peak vertical GRF has also been associated with lower joint loading at the knee and hip following a decrease in SL by 10% however the mechanical responses to a 5% reduction were more favourable[7].

Mechanisms underpinning changes in lower body loading associated with a shorter SL include increased knee flexion at initial ground contact and reduced foot inclination angle[8] leading to altered foot strike patterns. Runners with a fore-foot strike pattern experience a lower knee abduction moment when compared to those with a rear-foot strike[9]. A reduction in SL can also reduce the peak hip adduction angle[7] but the association between this and patellofemoral pain is inconclusive[10]. Gait retraining aimed at reducing knee pain can result in a shift in loading to the other lower body joints, including increased soleus activation and negative work experienced at the ankle joint[7]. Despite possible transferral of injury sites, distributing shock attenuation across multiple joints is beneficial, with Barton et al.[11] concluding that gait retraining is effective in reducing patellofemoral pain and lower-limb injury. Additionally, further research is required to understand the mechanisms underpinning the changes that occur.

Gait retraining studies have adopted various methods in combination with running to facilitate desired changes in running gait, for example, Willy et al.[12] used mirrors to provide runners with visual feedback of lower extremity alignment during treadmill running. To the best of our knowledge, however, studies are yet to adopt methods to reinforce this motor (re)learning in addition to gait retraining sessions. Video self-modeling, which refers to a person viewing video recordings of their task performance, has been shown to improve motor learning across actions varying in[13]. Observing one's own performances helps develop error detection/correction and enhances form of movement execution[14], making this an ideal supplementary tool for gait retraining.

Given the physical nature of injuries, it is understandable that previous gait retraining literature has focused on changes in physical responses (eg, loading patterns) that result from this intervention. However, this approach fails to consider the impacts of gait retraining upon runners' cognitions and emotions that may be associated with changes in behavior. Brewer[15] highlights the need to test the psychological effects of injury interventions in a bid to achieve successful return to physical activity/sport and decrease the incidence of re-injury. Therefore, this study aims to examine the biomechanical and psychological effects of a four-week gait retraining and video self-modeling intervention designed to reduce SL by 2-4% in habitual runners who experience chronic lower-level knee pain.

2 METHODS AND MATERIALS

2.1 Participants

Two female participants with a rear foot-strike pattern volunteered to take part in the study. Criterion for inclusion in the study was that both participants performed a minimum of two 5km runs/week despite experiencing anterior knee pain. Participants were otherwise healthy and completed a written consent form and health screen questionnaire, as approved by the ethical panel of the first author's University.

Participant 1. Football player (age: 24 years, mass: 49.8kg, height: 1.62m) who experienced a ruptured anterior cruciate ligament 4 years previous. Her mean pre-test perceived impact of knee pain (PIQ-6[16]) score of 43.25 was categorised as "little/no" perceived impact of knee pain when starting this study.

Participant 2. Recreational runner (age: 23, mass: 63.7kg, height: 1.60m) who experienced anterior knee pain and consequently her ideal exercise regime was curtailed. Her mean pre-test PIQ-6 score of 45.5 was categorised as "little/no" perceived impact of knee pain when starting this study.

2.2 Study Overview

This study adopted a pre-test – post-test experimental study design across an eight-week period. During the two-week pre-test phase, participants completed a biomechanical gait analysis and recorded self-reported values for psychological variables associated with performance and injury by completing a psychological survey pack. Over a further two-week period, four gait retraining (GR) running sessions were conducted during which verbal and auditory SL and SF feedback were provided, three times at eight minute intervals over during 30 minute run. Participants then performed two-weeks of gait consolidation (GC) where the four gait retraining running sessions were repeated but verbal and auditory feedback were removed. Following each 30 minute run the participants completed the psychological survey pack. Participants viewed the video self-modeling interventions at least twice daily in between sessions for both gait retraining and consolidation periods. Finally, participants repeated the biomechanical gait analysis and completed the survey pack across a two-week post-test phase.

2.3 Biomechanical

Data collection. Anthropometric measures were recorded, and 16 reflective passive markers were placed on hairless skin at pre-defined anatomical landmarks to create a three-dimensional lower body spatial model[17]. Participants performed ten successful running trials at a self-selected velocity (±5%), which had been pre-determined during familiarisation. A successful trial was determined by a participant meeting the desired running velocity (determined from timing gates) and making full right foot contact with an uncovered force plate. Three-dimensional coordinate and ground reaction force data were collected for each running trial using a twelve camera Vicon motion-capture system (sample rate = 100Hz;

Vicon™, Oxford UK) synchronised with two force plates (sample rate = 1000Hz; Kistler™, Switzerland, 9281C).

Data processing. The x, y and z coordinate and force data were filtered using a low-pass fourth-order Butterworth filter with a cut-off frequency of 50Hz and 8Hz, respectively. The lower body joint centres were determined from the coordinate data and lower body joint angles, moments and power were calculated using vector-defined segments and standard inverse dynamics. The stance phase was analysed and defined from initial (vertical GRF >10N) to final (vertical GRF<10N) contact with a force plate. During stance, selected temporal variables were examined during the first 50ms (loading phase: LP) and at the time of first vertical peak GRF (impact peak: IP).

Mean and standard deviation values were determined for discrete and continuous variables from the ten successful running trials. The discrete vertical, rate of vertical and horizontal GRF are reported. The ankle dorsi, knee flexion and foot (to the ground) angles at initial ground contact and maximal range of ankle dorsi and knee flexion during the stance phase are also reported. Peak powers and moments were determined in the LP. The horizontal displacement of the lateral ankle joint markers were used to calculate SL from initial contact with the plate to floor contact of the contralateral foot, from which SF was determined. At initial ground contact the horizontal displacement of the lateral right ankle joint marker to the centre of the pelvis was reported. The vertical and horizontal GRF continuous profiles were examined throughout stance. Data sets were converted to 100% of stance by interpolation of the data using a cubic spline (MatLab, version 2013a).

2.4 Psychological

Data collection. Participants completed a psychological survey pack at eight time-points across this study (four per test phase). Scores were recorded for the following variables at all time-points; task self-efficacy for optimal running gait[18] running maintenance and recovery self-efficacy[19] intrinsic motivation to run (adapted subscale from SMS-6[20]) worry about knee pain (adapted subscale from SAS-2[21]), positive and negative affect (I-PANAS-SF[22]), general self-efficacy[23], and perceived impact of knee pain (PIQ-6[16]). Composite values were computed for psychological variables according to respective questionnaire guidelines (i.e., mean or total values for all items).

2.5 Gait retraining and consolidation sessions

Participants completed a total of thirty minutes running on a motorised Woodway treadmill (PPS55-MED) per session. After this, each participant ran at their self-selected velocity for three eight-minute blocks, totalling twenty-four minutes running. To determine the SL, video footage was recorded in the frontal plane using a slow-motion iPhone camera (sample rate = 240Hz) and the iOS app RunMatic to obtain SF. Ninety seconds before the end of each eight-minute block, standardised verbal feedback was provided to the participants: "please shorten/lengthen/maintain your current stride length in time with the metronome". After this, auditory feedback was delivered using a metronome that corresponded with the time of initial ground contact for the participant's optimal gait cycle (i.e., 3% SL reduction from pre-test values). The GC protocol mirrored GR sessions, but the verbal and auditory feedback were removed.

2.6 Video self-modeling

The last three minutes of all GR blocks were video recorded in the sagittal plane to provide footage for the session-specific self-modeling videos. Each self-modeling video included three repetitions of the nine clips, totalling two minutes fifteen seconds of footage. Video clips displaying ideal SL from the GR sessions were used as the self-modeling videos during GC. The participants viewed the self-modeling videos twice daily during the four-week intervention period.

2.7 Data analysis

Biomechanical. For the mean discrete variables, the mean difference and the effect size (*ES*) was calculated using Cohen's d and corrected for a small population size using Hedges g. The waveform GRF data were examined for significant differences between pre- and post-test phases using open-source one-dimensional statistical parametric mapping (SPM1D[24]). A scalar test statistic SPM (t) was calculated for each data point during the stance phase, producing a statistical parametric map. The alpha level was set at 0.05 and temporal smoothness from the average temporal gradient was produced using random field theory[24]. Significance was defined when the test statistic (t) was greater than the critical threshold determined from the random field theory.

Psychological. The mean (±standard deviation) value for each computed variable was determined from the four time-points per test phase. The *ES* was calculated using Cohen's d and corrected for a small population size using Hedges g.

3 RESULTS

3.1 Participant 1

Biomechanical. Following the intervention, P1 achieved the desired change in SL (M_{diff} = -2.61%, *ES* = 0.64) and a corresponding increase in SF (M_{diff} = -3.44%, *ES* = 0.81). The SPM waveform analysis, illustrated in figure 1, revealed significant decreases in vertical (9.03%) and horizontal GRF (19.05%) during LP. A decreased ankle dorsi-flexion (*ES* = 2.38) and increased knee flexion (*ES* = 5.60) were found at initial ground contact following the intervention. Conversely the range of dorsi-flexion increased, and knee flexion decreased in the LP. Peak knee abduction moment decreased (M_{diff} = -72.04%, *ES* = 1.67) and hip adduction moment increased (M_{diff} = 26.39%, *ES* = 0.96) during the LP.

Psychological. For performance-based psychological variables, P1 demonstrated large positive changes in task self-efficacy for optimal running gait (M_{diff} = 25.00%, *ES* = 4.30), running maintenance self-efficacy (M_{diff} = 26.98%, *ES* = 3.48), running recovery self-efficacy (M_{diff} = 8.96%, *ES* = 1.70), and intrinsic motivation to run (M_{diff} = 17.33%, *ES* = 3.17), but no change in worry about knee pain after the intervention. For injury-based psychological variables, P1 demonstrated large positive changes in general self-efficacy (M_{diff} = 5.97%, *ES* = 3.00) and perceived impact of knee pain (M_{diff} = -7.51%, *ES* = 0.85), a large negative change in positive affect (M_{diff} = -5.26%, *ES* = 1.50), and a moderate negative change in negative affect (M_{diff} = 2.56%, *ES* = 0.61) after the intervention.

3.2 Participant 2

Biomechanical. Following the intervention, P2 achieved a 0.01 m (0.90%) decrease in SL (*ES* = 0.38) and a 1.06% increase in SF. Significant increases in vertical and horizontal GRF were found in the first 5% of the stance phase (see figure 2), although the change in peak values were deemed small (*ES* = 0.24). A large increase in the rate of vertical GRF to IP was reported. At initial ground contact the ankle and knee angles decreased, with 1^{o} greater dorsi-flexion and 48.78% more knee flexion. During the LP the peak ankle negative power (M_{diff} = -56.31%, *ES* = 0.97) and knee abduction moment decreased (M_{diff} = -87.50%, *ES* = 1.14) and the hip adduction moment increased by 22.89% (*ES* = 1.30).

Psychological. For performance-based psychological variables, P2 demonstrated large positive changes in task self-efficacy for optimal running gait (M_{diff} = 20.00%, *ES* = 3.20), intrinsic motivation to run (M_{diff} = 16.46%, *ES* = 3.17), and worry about knee pain (M_{diff} = -20.00%, *ES* = 3.00), a moderate negative change in running maintenance self-efficacy (M_{diff} = -2.74%, *ES* = 0.23), and a large negative change in running recovery self-efficacy (M_{diff} = -20.25%, *ES* = 3.65) after the intervention. For injury-based psychological variables, P2 demonstrated large positive changes in general self-efficacy (M_{diff} = 22.22%, *ES* = 4.30) and positive affect (M_{diff} = 19.44%, *ES* = 4.29), a small positive change in perceived impact of knee pain (M_{diff} = -1.65%, *ES* = 0.27), and a small negative change in negative affect (M_{diff} = 2.78%, *ES* = 0.24) after the intervention.

4 DISCUSSION

The aim of this multidisciplinary pilot study was to assess the acute effects of a combination of verbal, auditory and video self-modeling feedback, to reduce SL by 2-4%, on lower-limb loading, knee pain and psychological responses for two habitual runners. P1 achieved the desired change in SL and a 7.5% reduction in her knee pain score whereas P2 produced a 1.3% shorter SL and a lower knee pain score by 1.6%.

4.1 Biomechanical

The significant reduction in the vertical GRF at IP for P1 suggested an enhanced dampening of force attenuation. Attenuation occurs through energy absorption from active muscles, and deformation of passive tissues, the latter being the heel fat pad, ligaments, bone, muscle oscillation, articular cartilage and footwear. The significant decrease in braking GRF corresponding with a reduction in anterior foot displacement relative to the pelvis is in agreement with Liebermann et al.[25] Conversely, for P2 the decreased SL increased shock attenuation which becomes meaningful in terms of injury risk. The rate of vertical GRF to IP increased for both participants following the combined intervention suggesting a shorter time to IP, which would seem to be a logical progression following increased SF[26]. The importance of muscle pre-activation to attenuate the rate of vertical GRFs, particularly for the hamstrings, has been highlighted[27], which appear to have been impaired for both participants following the combined intervention. In terms of running performance, the significant increase in vertical and horizontal propulsive GRF of P1 potentially enhanced the flight phase of gait. This suggests a more efficient use of the stretch-shortening cycle by utilising an initial strike pattern that is close to the mid-foot[28] and producing greater propulsive force, whilst reducing the braking force[29].

The ankle and foot angles at initial ground contact increased for P1, indicating that the strike pattern moved away from rear-foot. Consequently, the velocity of dorsi-flexion may have increased, leading to increased negative work and additional loading at the ankle joint. Such altered load may cause Achilles tendinopathy and calf muscle strain if the soft tissues are unprepared[30]. The relatively unchanged sagittal plane ankle kinematics for P2 and the increased GRF suggests that this four-week intervention programme was maladaptive for this individual. In agreement with previous research, P1 demonstrated increased peak ankle negative power following the intervention[8]. The change in ankle position at initial ground contact, greater power, and the range of dorsi-flexion would result in a required amplification of ankle eccentric energy absorption[7].

The greater knee flexion at initial ground (P1,P2) contact post-intervention, is a supported finding from most studies assessing SL manipulation[7]. Hamstring activation during ground contact increases with greater knee flexion, providing muscular stabilisation of the joint[31]. Improvements in stabilisation have been associated with a reduction in anterior knee pain[32] and could explain the reduction of the peak abductor moments and the lower knee pain scores. The 5^{o} knee flexion during the GRF attenuation for P1 following the intervention may explain the decrease in pain score since knee flexion has been linked to patellofemoral force. Little change occurred in peak negative knee power in LP, however the increase in frontal plane peak hip adduction moment for both participants was not a positive outcome due to its reported association with patellofemoral pain and illiotibial band syndrome[33].

4.2 Psychological

Both participants experienced large increases in task self-efficacy for optimal running gait and intrinsic motivation to run post-intervention. Feedback is typically considered in terms of knowledge of results (KR) and knowledge of performance (KP). According to Magill and Anderson[34], KR refers to feedback associated with the outcome of a movement relative to its environmental goal (eg, if SL is above/at/below a target threshold), whereas KP refers to feedback on the movement pattern itself (eg, the observable foot strike patterns during running gait). Exposure to the two feedback types has led to increased task self-efficacy and intrinsic motivation for athletes/exercisers across simple and complex tasks[35]. Therefore, we suggest that the provision of KR in the GR sessions, and KR and KP in the self-modeling videos resulted in greater levels of task self-efficacy and intrinsic motivation in both runners. The runners reported large increases in general self-efficacy, reduced perceived impact of knee pain, and increased negative affect post-intervention. As the intervention targeted (re)learning of gait to reduce SL it is understandable that the runners perceived the knee pain to be less impactful towards their daily living and became more confident in their ability to perform well. It was surprising that both participants showed increased negative affect despite the improvement in general self-efficacy, as the two concepts have displayed inverse associations in past literature[36]. Studies have shown that athletes negative affect tends to diminish across the rehabilitation process, if deemed successful[37]. For P2, it is possible that this is associated with her sub-optimal performance during the intervention that ultimately resulted in a less than desirable reduction in SL.

P1 completed the intervention successfully and recorded increased confidence in her ability to maintain participation in running and recovery after a running-related setback. However, P2 did not achieve the desired change in SL and subsequently decreased confidence in these two aspects. In agreement with Bandura's[38] assertion that mastery experiences are the strongest source of efficacy beliefs, and can be provided via task completion and/or video self-modeling[13], we suggest that P1 increased running maintenance and recovery self-efficacy by gaining positive mastery experiences during GR sessions and when watching the self-modeling videos in between sessions. P1 recorded no change in worry about knee pain and a decrease in positive affect after the intervention, whereas P2 recorded decreased worry and increased positive affect upon completion. Worry and positive affect are opposing constructs in terms of emotional valence. Injuries expose athletes to a host of negative emotions[39], whereas high self-efficacy has positive emotional outcomes[38]. Based on the self-efficacy and knee pain scores, it is surprising that P1 and P2 have recorded such responses for worry and positive affect as these oppose robust findings from the literature. P1 had the lowest possible score for worry when starting the intervention, making a reduction impossible, but positive affect was not at a ceiling level. It is reasonable to conclude that changes in positive affect are not solely based on the intervention.

4.3 Limitations: The number of participants in this study restricted the statistical analysis, which provides additional meaning to the outcome measures and their application to a larger population. The long-term effect of the SL change are unknown and future work recommends additional participants and monitoring over a longitudinal period of time.

4.4 Conclusion: Both participants reported reductions in their perceived impact of knee pain scores following the combined gait retraining and video self-modeling intervention to reduce the SL. The exaggerated knee flexion at initial ground contact for the two runners' post-intervention potentially contributed to a reduced peak abduction moment. No changes were reported in negative knee power in LP indicating that they are not susceptible to contracting patellofemoral pain in the future. The two participants recorded largely positive responses for psychological variables associated with performance and injury. However, the participant that achieved the desired reduction in SL demonstrated more and larger positive effects in comparison to the participant that did not achieve this outcome. The study findings support the use of combined gait retraining and video self-modeling for runners experiencing chronic knee pain. Despite this suggestion, our results also outline the importance of individualisation when designing gait retraining programmes. Specifically, we suggest that intervention based protocols are designed the achievement of a desired change (ie, 2-4% SL reduction) rather than a fixed number of sessions spanning a set time-period.

5 PERSPECTIVES

Two participants completed the intervention, where the aim was to reduce SL by 2-4% and examine the biomechanical and psychological responses. The successful change in SL caused reduction in the shock attenuation and consequently the energy absorption requirements of the bone, cartilage, tendon and muscular contraction. A flexed knee at initial ground contact, which has been associated with a reduced knee extensor and peak knee abductor moments, along with less knee flexion during the loading phase potentially contributed to the reported reduction in the perceived impact of knee pain score. Subsequently, this lead to several positive changes in psychological variables associated with injury and running performance. In the situation where the reduced SL was less than 2% there were a myriad of responses, some of which were injury provoking particularly when considered with the induced increase in the number of collisions with the ground. This undesirable change in SL also resulted in mixed changes in psychological variables associated with injury and running performance. Taken together, this suggests the need to tailor the intervention to the individual by incorporating a flexible intervention period whereby each runner completes the programme once the desired SL change is achieved.

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FIGURE 1 illustrates the mean vertical and horizontal GRF curves which are normalised over the stance phase (%) for participant 1. Underneath are the statistical parametric maps where the shaded areas indicate significant differences pre- and post-testing phases.

FIGURE 2 illustrates the mean vertical and horizontal GRF curves which are normalised over the stance phase (%) for participant 2. Underneath are the statistical parametric maps where the shaded areas indicate significant differences pre- and post-testing phases.

TABLE 1 The mean ± standard deviation (SD) Biomechanical variables and knee pain score from the pre and post testing phases for Participant 1

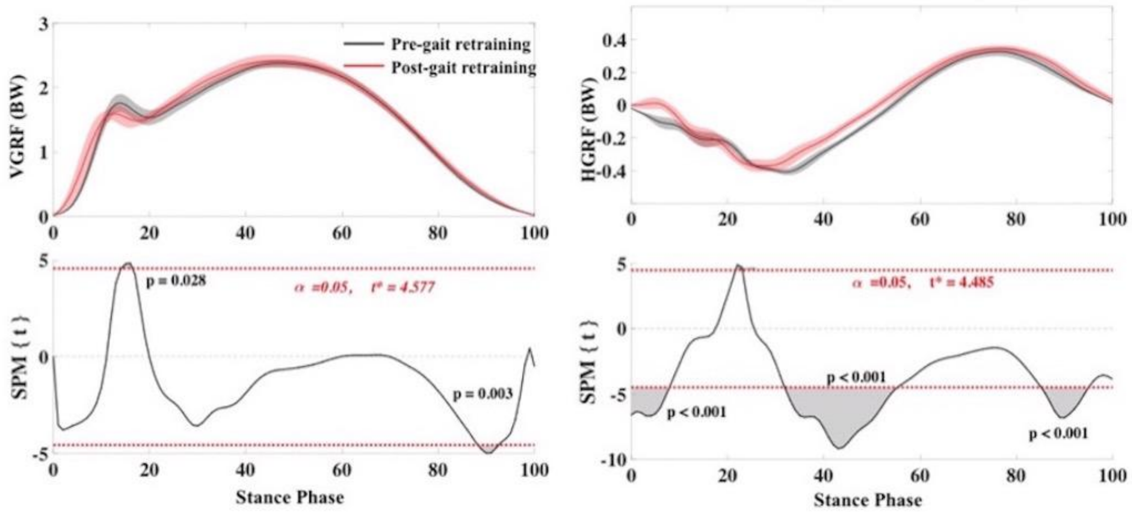
Participant 1

Variable	**Pre-Testing**	**Post-Testing**	***Mean**$_{diff}$* **(%)**	***Effect Size* (Hedges g)**
	Mean ± SD	**Mean ± SD**		
Vertical GRF @ IP (BW)	1.77 ± 0.14	1.61 ± 0.12	-9.03	1.18
Horizontal GRF @ IP (BW)	0.21 ± 0.04	0.17 ± 0.05	-19.05	0.85
Rate of Vertical GRF to IP ($BW \cdot s^{-1}$)	56.70 ± 5.11	59.00 ± 5.17	4.16	0.43
Step Frequency (Hz)	2.91 ± 0.05	3.01 ± 0.16	3.44	0.81
Step Length (m)	1.15 ± 0.02	1.12 ± 0.06	-2.61	0.64
Foot angle to the horizontal @ initial ground contact (^{o})	15.80 ± 5.85	17.43 ± 2.80	10.32	0.34
Displacement of the Right Ankle Relative to Pelvis @ Initial Ground Contact (m)	0.19 ± 0.01	0.17 ± 0.02	-10.53	1.21
ANKLE				
Joint Angle (^{o})				
Initial Ground Contact	7.70 ± 1.49	4.72 ± 0.81	-38.70	2.38
Range of Dorsi-Flexion	13.80 ± 1.60	17.40 ± 0.68	26.09	2.80
Peak Negative Power in LP ($W \cdot kg^{-1}$)	0.52 ± 0.21	1.70 ± 0.70	226.92	2.19
KNEE				
Joint Angle (^{o})				
Initial Ground Contact	11.20 ± 1.42	21.20 ± 1.96	89.29	5.60
Range of Flexion	30.60 ± 2.28	25.60 ± 2.77	-16.27	1.89
Peak Abduction Moment in LP ($Nm \cdot kg^{-1}$) x 10^{-1}	0.93 ± 0.38	0.26 ± 0.39	-72.04	1.67
Peak Negative Power in LP ($W \cdot kg^{-1}$)	9.73 ± 0.99	10.30 ± 1.44	5.86	0.44
HIP				
Peak Adduction Moment in LP ($Nm \cdot kg^{-1}$)	0.72 ± 0.12	0.91 ± 0.24	26.39	0.96

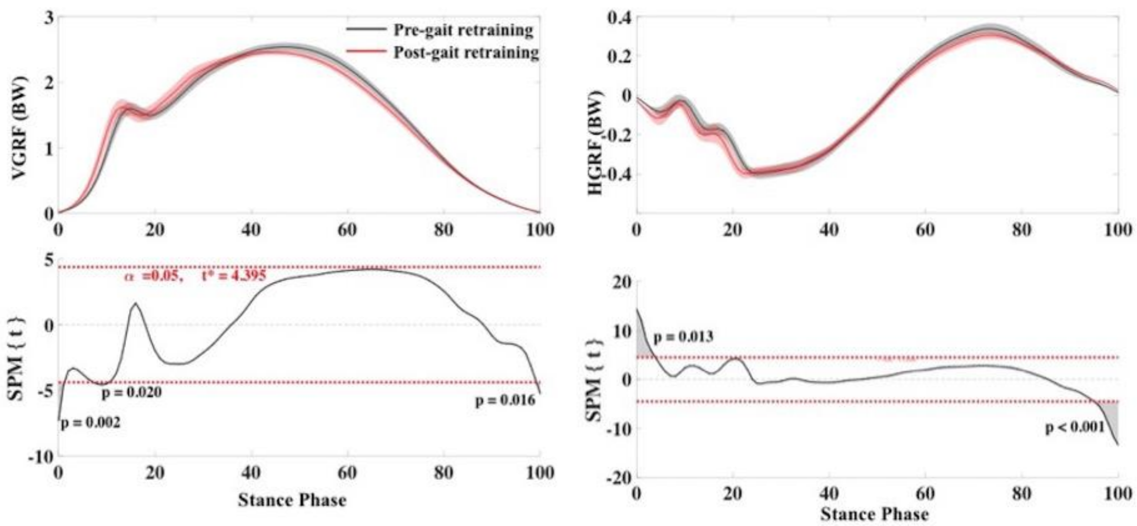
TABLE 2 The mean ± standard deviation (SD) Biomechanical variables and knee pain score from the pre and post testing phases for Participant 2

Participant 2

Variable	**Pre-Testing**	**Post-Testing**	***Mean$_{diff}$* (%)**	***Effect Size* (Hedges g)**
	Mean ± SD	**Mean ± SD**		
Vertical GRF @ IP (BW)	1.61 ± 0.11	1.64 ± 0.13	1.86	0.24
Horizontal GRF @ IP (BW)	0.19 ± 0.04	0.20 ± 0.04	5.26	0.24
Rate of Vertical GRF to IP (BW·s^{-1})	46.60 ± 3.77	52.10 ± 4.58	11.80	1.26
Step Frequency (Hz)	2.82 ± 0.07	2.85 ± 0.05	1.06	0.47
Step Length (m)	1.11 ± 0.03	1.10 ± 0.02	-0.90	0.38
Foot angle to the horizontal @ initial ground contact (^{o})	15.35 ± 3.78	8.00 ± 3.62	-47.88	1.38
Displacement of the Right Ankle Relative to Pelvis @ Initial Ground Contact (m)	0.17 ± 0.01	0.17 ± 0.01	0.00	0.00
ANKLE				
Joint Angle (^{o})				
Initial Ground Contact	12.90 ± 1.32	13.90 ± 1.22	7.75	0.75
Range of Dorsi-Flexion	14.00 ± 2.26	13.30 ± 1.12	-5.00	0.38
Peak Negative Power in LP (W·kg^{-1})	1.03 ± 0.79	0.45 ± 0.16	-56.31	0.97
KNEE				
Joint Angle (^{o})				
Initial Ground Contact	13.51 ± 1.06	20.10 ± 1.56	48.78	4.73
Range of Flexion	25.80 ± 1.19	25.90 ± 1.14	0.39	0.08
Peak Abduction Moment in LP (Nm·kg^{-1}) x 10^{-1}	0.56 ± 0.43	0.07 ± 0.39	-87.50	1.14
Peak Negative Power in LP (W·kg^{-1})	13.20 ± 0.79	13.50 ± 2.39	2.42	0.16
HIP				
Peak Adduction Moment in LP (Nm·kg^{-1})	0.83 ± 0.15	1.02 ± 0.13	22.89	1.30



Pre-gait retraining
Post-gait retraining
VGRF (BW)
HGRF (BW)
SPM { t }
p = 0.028
α =0.05, t* = 4.577
p = 0.003
α =0.05, t* = 4.485
p < 0.001
p < 0.001
p < 0.001
Stance Phase
Stance Phase



Pre-gait retraining
Post-gait retraining
VGRF (BW)
HGRF (BW)
SPM { t }
α =0.05, t* = 4.395
p = 0.020
p = 0.002
p = 0.016
p = 0.013
p < 0.001
Stance Phase
Stance Phase