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Influence of hip flexion angle on strength and gluteal muscle activities in the clinical pilates clamshell exercise

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ABSTRACT

The study aimed to investigate the presence of directional preference using the Clinical Pilates method of clamshell exercise among relatively healthy young adults, and the influence of hip flexion angles on maximum isometric strength (handheld dynamometer) and muscle activities (electromyography). The clamshell assessment involves testing in varying angles of hip flexion (0°, 30°, 60° and 90°) and 21 participants were tested. Directional preferences in the transverse and anteroposterior axes of movements were present among the participants. Gluteus medius activation was highest in the non-problem side across all hip flexion angles. In contrast, the problem side showed dysfunction of the gluteus medius, especially at the 60° hip flexion angle, 0.89 unit (ratio of maximal voluntary isometric contraction) reduction per 1 N force exerted, 95% CI -1.69 to −0.09, $p = 0.031$. Comparison against the non-problem side found gluteus medius activity lower on the problem side, mean difference (SD) was 26.2 (56.1), $p = 0.045$. Therefore, directional preference is not limited to people with injuries and can exist in healthy individuals or people who have recovered from injuries. The gluteus medius was identified to be dysfunctional on the problem side and Clinical Pilates clamshell assessment is potentially useful in assessing for motor coordination impairment.

1. Introduction

Low back pain is a highly prevalent musculoskeletal condition that affects people around the world (Hoy et al., 2014; Yeo and Tay, 2009). General Pilates and McKenzie exercise methods were identified in recent systematic review as favourable forms of exercise interventions to manage people with chronic low back pain (Hayden et al., 2021). The Dance Medicine Australia (DMA) Clinical Pilates exercise method is an integration of both the aforementioned exercise methods (Tulloch et al., 2012), but studies investigating the method is scarce. Although the DMA Clinical Pilates exercise method demonstrated similar efficacy as general exercises in the longer term (Wajswelner et al., 2012), a smaller study could not reproduce similar results (Devasahayam et al., 2016). This could be due to a gap in the understanding of the DMA Clinical Pilates assessment method.

Previous Clinical Pilates study explored the assessment of movements into trunk-hip flexion against extension (transverse axis) (Tulloch et al., 2012), but movements about the anteroposterior axis, which is trunk lateral flexion with hip abduction, has not been studied. The Clinical Pilates exercise method identifies directional preference and unilateral bias (Tulloch et al., 2012), and the symptomatic side (e.g pain) does not always translate to unilateral bias (Taylor et al., 2011). The clamshell exercise, a combination of hip abduction and external rotation, is used as an assessment for presence of lateral bias in Clinical Pilates (Kwok et al., 2021), but current studies have not studied individuals based on their directional preference (Macadam et al., 2015). A study identified hip flexion angle of 60° as the optimal angle in performing the clamshell exercise for optimal gluteal muscle activation, primarily gluteus medius (GMed) among healthy adults (Willcox and Burden, 2013). However, a recent systematic review found that the recommended angle varied between studies (Macadam et al., 2015). The difference in findings between studies is not surprising because the clamshell exercise is a combination of hip abduction and external rotation, so several muscles will be involved and not limited to GMed (McBeth et al., 2012; Reiman et al., 2012). Non-weightbearing exercises in side-lying was also found to be more beneficial for gluteal muscle activation as compared to standing non-weightbearing exercises (Bolgla and Uhl, 2005). Thus, the use of clamshell exercise as an assessment for motor coordination impairment in Clinical Pilates could be appropriate.

The DMA Clinical Pilates assessment method evaluates the strength

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of the clamshell movement instead of muscle activity to classify the optimal angle to perform the clamshell exercise for an individual. However, the DMA Clinical Pilates assessment using the clamshell movement has not been studied previously. Therefore, this study was undertaken to investigate the use of clamshell exercise to identify directional preference of young adults. We hypothesise that the use of handheld dynamometer (HHD) will be able to objectively identify directional preference. In addition, we studied the association between strength of the clamshell movement against muscle activation of gluteus maximus (GMax), GMed and tensor fascia latae muscles (TFL). It is hypothesised that the gluteal muscles activation will be moderately correlated with strength. Lastly, the study aimed to explore presence of dysfunctional muscle activity on the problem side (lateral bias) of adults.

2. Methods

2.1. Study design

This cross-sectional study was conducted by the authors. To minimise researcher bias, the first two authors who were involved in data collection and analysis were not trained in the Clinical Pilates exercise method. They were trained sufficiently in the use of surface electromyography (EMG) and HHD. Data collection were completed in a quiet and secured access laboratory in the Singapore Institute of Technology from August to December 2020. This study was registered with the Australian New Zealand Clinical Trial registry (ACTRN12621001142820).

2.2. Participants

To date, there is no study data available to compare data at 0° and 90° hip flexion angle, hence an estimate is made based on the comparison of gluteus muscle activation in 0° and 60° hip flexion angle (Willcox and Burden, 2013), where the mean difference of ratio of maximal voluntary isometric contraction (%MVIC) is 5.2% and a standard deviation of 5%. However, the study projected heterogeneity among participants to qualitatively categorise participants based on directional preference, so a smaller mean difference (4%) and a larger standard deviation (10%) is assumed, which translated to an effect size of 0.4. Using G*Power version 3.1 F-test (4 × 4), 90% power, 5% type I error and effect size of 0.4, a total sample size of 20 is required. Factoring a 10% drop-out risk, we aimed to recruit 22 participants for the study.

Participant recruitment was open to the public, as well as staff and students of the Singapore Institute of Technology. Public recruitment was assisted by the Singapore Physiotherapy Association via electronic poster. We screened 55 participants and 21 participants were eligible based on the inclusion and exclusion criteria. The inclusion criteria to participate in the study are English proficiency (spoken and written), age 21 years and above, no skin allergy and absence of lower quadrant (lower back and lower limbs) injury or pathology in the recent 6 months. Because surface EMG was used in the study, participants with BMI above 25 kg/m^2 were excluded. Participants with neck, shoulder and lower quadrant conditions of 6 months recency were also excluded. Prior to the study participation, all eligible participants provided informed consent in accordance with the requirements of the Singapore Institute of Technology Institutional Review Board, project number 2020102.

2.3. Practice trial

Before data collection, participants completed a practice session of the clamshell exercise in four hip flexion angles (Appendix 1): 0° (extension bias), 30° (mid-range extension bias, MR1), 60° (mid-range flexion bias, MR2) and 90° (flexion bias), on both legs to ensure accurate execution of the exercise without compensatory movements. Hip flexion angles were measured using a goniometer, which is a reliable tool in measuring joint range of motion (Ekstrand et al., 1982). Participants were positioned in side-lying on a stable plinth, hip and knees flexed, and head supported by a pillow (Fig. 1a). Participants were instructed to keep the medial borders of their feet together as they abducted and externally rotated their hips until the knee was levelled with the ipsilateral pelvic crest (Fig. 1b), which prevents compensatory movements from the trunk. Once participants were prepared to commence testing procedures, they were given a 5-minute break.

2.4. EMG testing procedures

2.4.1. Electrode placement

Prior to electrode placement, the areas (gluteal and hip regions) were shaved followed by alcohol swabs to prepare the participants' skin to reduce impedance and noise. The electrode positions for the GMax, GMed and TFL were identified using landmarks described in past study (Rainoldi et al., 2004) – GMax: 34% distance from S2 vertebrae to greater trochanter; GMed: 33% distance from greater trochanter to iliac crest; TFL: 7.5 cm from the anterior superior iliac spine to a line oriented 30° anteriorly from the line joining anterior superior iliac spine and greater trochanter, see Fig. 2. In total, six wireless surface EMG electrodes were placed on both sides of the muscles with at least 2 cm distance between electrodes.

All EMG signals were recorded via the Delsys Trigno Avanti Sensor, a wireless surface EMG electrode, and EMGworks® acquisition software (Delsys Inc). EMG signals were sampled at 4370 sa/sec and amplified at a bandwidth of 20–450 Hz with baseline noise of 750 nV, and a common mode rejection ratio of <80 dB. EMGworks® software (Delsys Inc) was used to process raw EMG signals of maximal voluntary isometric contraction (MVIC) for clamshell strength testing. The amplitude of the EMG signals was obtained using root-mean-square (RMS) method (Farfan et al., 2010).

2.4.2. MVIC testing

For normalisation of clamshell exercise EMG signals, MVIC of the GMax, GMed and TFL muscles were measured bilaterally according to previous established protocol (Selkowitz et al., 2013). Participants performed a 5-s MVIC testing twice with a 30-s rest between repetitions and a 3-min break between each muscle tested. To standardise movement resistance during the testing, a gait belt was strapped just above the knees of the participant and around the plinth. The belt was adjusted to limit movement beyond the break test position of each muscle (Schmidt et al., 2013). To minimise positional changes, MVICs were assessed in the following order: 1) left then right GMax, 2) left GMed then left TFL and 3) right GMed then right TFL. GMax MVIC was tested by performing resisted hip extension in prone lying with knees flexed to 90°. GMed MVIC was assessed with participants performing resisted hip abduction in side-lying with their test leg on top and hip and knee extended to 0°, while the bottom leg hip and knee flexed for stabilisation. TFL MVIC testing was similar to GMed except with the tested hip is flexed at 45°. Testing positions are shown in Appendix 2. Standardised verbal encouragements ("Do your best. Exert!") were provided for all participants during MVIC testing. Upon completion of MVIC testing, participants were given a 5-min break before commencing clamshell exercise strength testing.

2.5. Strength testing procedures

The clamshell exercise testing was performed in side-lying on the plinth with the spine in neutral and knees flexed to 90° across the four hip flexion angles tested. Participants performed 2 repetitions of 5-s hold of resisted hip abduction and external rotation as per practice trial with a 30-s rest between the repetitions. Participants were given 3-min rest breaks between each clamshell position testing. A gait belt was fastened around participants' legs and the plinth with a HHD attached and positioned just above the lateral condyle of the femur for concurrent

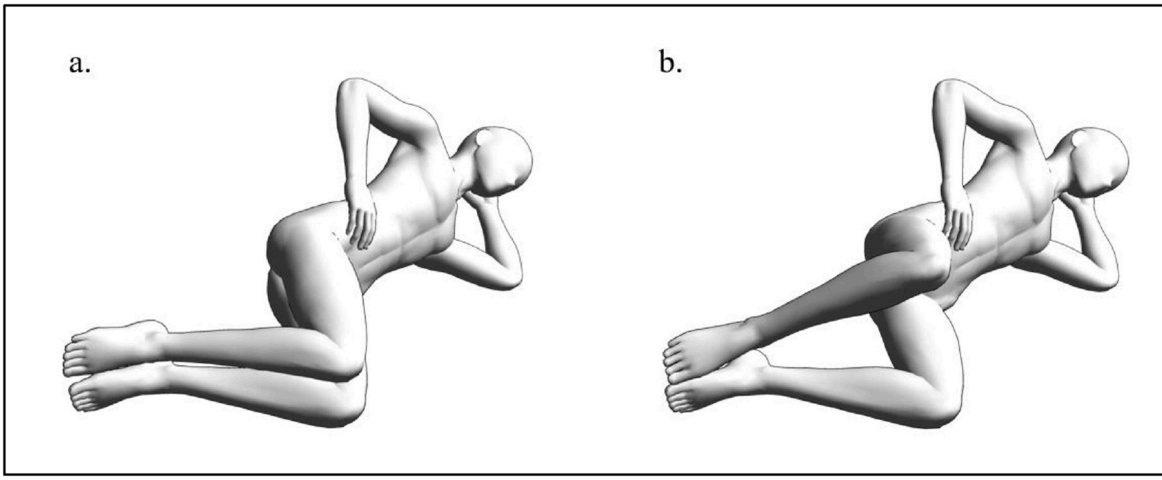

Fig. 1. (a) Clamshell starting position; (b) clamshell isometric testing position.

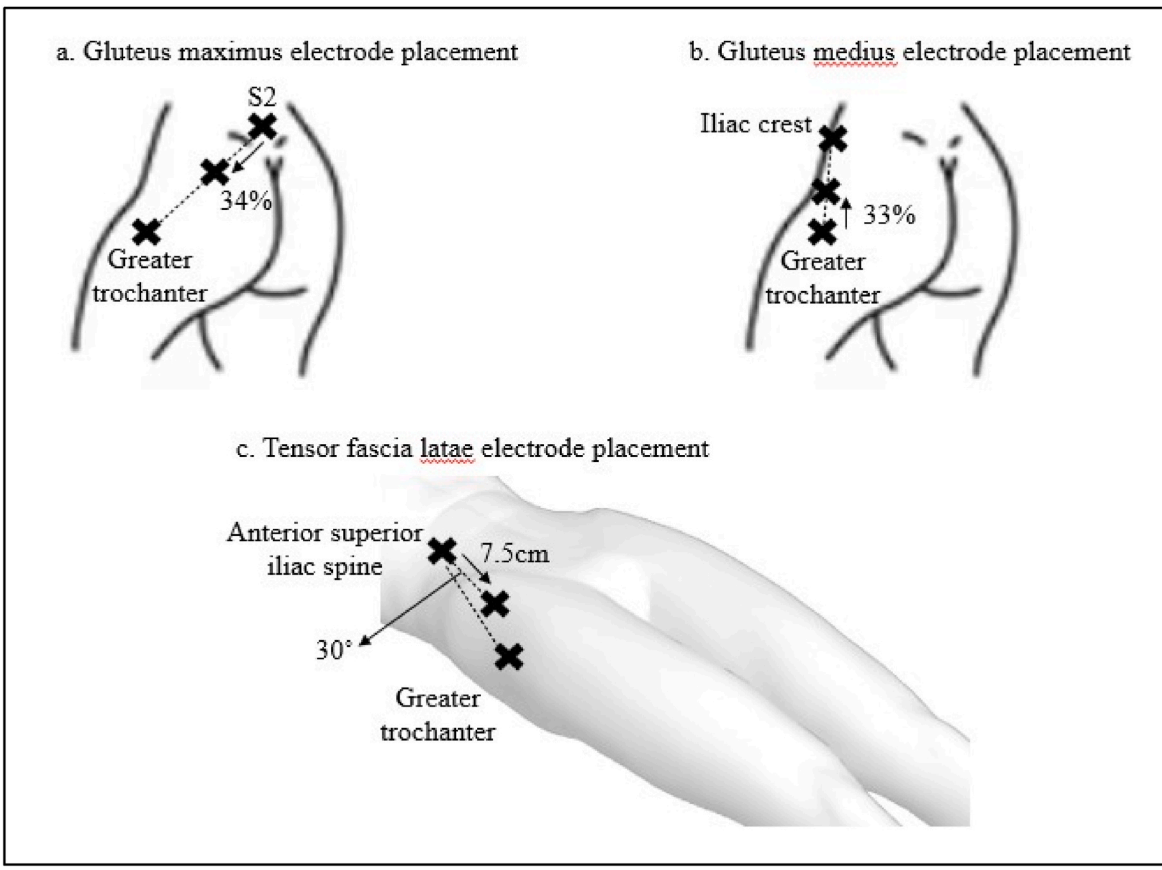

Fig. 2. Electromyography electrodes placement.

recording of muscle strength and muscle activities, see Fig. 3. Towel padding was used to reduce participant discomfort at the HHD to skin contact.

The HHD, wireless ergoFET digital force gauge (Hoggan Scientific, LLC) with the flat pad attachment, was fixated using a gait belt strap against the lateral aspect of the distal thigh of the participant to measure the force produced. Readings were measured by the device in kilogram-force (kgF). The assessor, RYTY, set-up the participants and device, and monitored for compensatory movements by the participants. Data was discarded for trials affected by compensatory movements in performing the clamshell exercise. The assessor informed all participants to exert force against the HHD maximally. BCK, a DMA Clinical Pilates certified physiotherapist with more than 10 years of clinical experience, assisted with the directional preference categorisation (Kwok et al., 2021).

2.6. Data analysis

The EMG signals from the clamshell movements were normalised against the MVIC values of the respective muscles and expressed as % MVIC. All EMG readings were manually analysed to identify error measurements (Konrad, 2005), which we defined as readings at least twice the value of the next highest reading for the participant. After

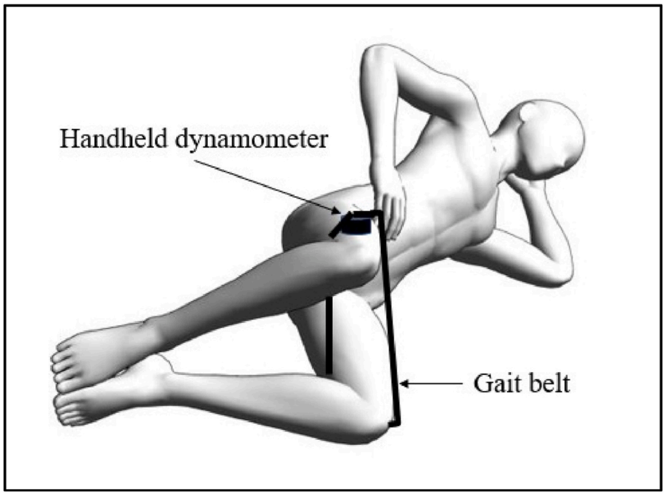

Fig. 3. Positioning of handheld dynamometer and stabilisation with gait belt.

excluding the error measurement, the highest EMG signal amplitude for each clamshell position was selected and used for statistical analysis.

HHD might produce erroneous readings (Chamorro et al., 2017), so the readings were manually analysed for abnormality against other values. After excluding error measurements, the problem side/lateral bias was manually identified as the leg with a greater difference between the lowest and highest HHD values. Thereafter, directional preference in the sagittal plane was determined via manual analysis of the highest HHD reading in the problem side. Because the HHD values were recorded in kgf, they were converted to international system of units, newtons (N), by multiplying each value by 9.807 N/kg.

2.7. Statistical analysis

All statistical analyses were performed using IBM SPSS statistical software (Version 23.0). Statistical significance was set at $p < 0.05$ for all statistical analyses. The non-problem side was not categorised into directional preference because the strength values were consistent between the four hip flexion angles of each participant, which was aligned with Clinical Pilates practice. The problem side of the participants was analysed in the respective directional preference groups: Extension, MR1, MR2 and flexion.

One-way analysis of variances (ANOVA) was performed to analyse the problem side for between- and within-group differences to investigate the effect of hip flexion angle on muscle strength and muscle activity of GMax, GMed and TFL, with Bonferroni adjustment for relevant post hoc test. To examine the relationship between clamshell strength and muscle activity at each hip flexion angle, separate Pearson's correlation analyses were performed to compare the HHD readings against the EMG readings of GMax, GMed and TFL. Strength of correlation was assessed using current literature (Schober et al., 2018). Linear regression was then used to first study the predictive validity of GMax, GMed and TFL activities on isometric strength of clamshell exercise on the non-problem side. If a model has any factor in the 3-factor regression model that approximates closely to statistical significance, regression analyses were repeated with 2 factors.

Linear regression was then similarly used to investigate the problem side without directional preference categorisation. If significant muscle activity abnormality was detected at any hip flexion angle, we compared the specific muscle activity at the specific angle between the non-problem and problem sides using paired t test. This will provide an understanding of muscle activity dysfunction in the problem side and considerations for rehabilitation.

3. Results

3.1. Study demographics

The demographics of the study participants are presented in Table 1 continuous variables as means (SDs) while categorical variables as frequency (%). Based on the directional preference classification, all participants were identified to have a problem side. In this study, the rate of the problem side corresponding to the dominant leg of the participant was 52.4%, ($n = 11$). Based on the directional preference classification, we found 12 participants (57.1%) with extension preference, 8 participants (38.1%) with mid-range extension preference (MR1), nil for mid-range flexion preference (MR2) and 1 participant (4.8%) with flexion preference. Due to the distribution of the directional preference groups, statistical analysis of the problem side could only be performed for comparisons between the extension preference and MR1 groups.

3.2. Clamshell isometric strength

The mean muscle strength of all participants for the non-problem side (0°, 30°, 60° and 90° hip flexion angles) are presented in Table 1. The mean strength of the problem side grouped by directional preference is shown in Fig. 4 and the mean (SD) presented in Table 2. The one-way ANOVA only found significant difference in strength between- and within-group (extension preference and MR1 groups) differences at 90° hip flexion angle, $F(2, 18) = 3.98$, $p = 0.037$. Further analysis revealed that the significant difference was not from between-group comparison, but yielded from within-group comparison. In the extension preference group, the clamshell strength at 90° hip flexion angle was significantly lower than other hip flexion angles, mean difference (SD): 63.8 (23.7) N, $p < 0.001$ (0° versus 90°), 41.0(18.8) N, $p < 0.001$ (30° versus 90°) and 27.1 (34.1) N, $p = 0.019$ (60° versus 90°). In the MR1 group, the clamshell strength at 90° hip flexion angle was significantly lower only when compared with the 30° hip flexion angle, mean difference (SD): 59.5 (34.0) N, $p = 0.002$ (30° versus 90°). In the extension preference

Table 1
Demographics of study participants ($n = 21$).

Demographics	Distribution
Age, mean (SD), years	23.8 (1.7)
Gender - male, n (%)	12 (57)
Height, mean (SD), m	1.68 (0.09)
Weight, mean (SD), kg	61.8 (8.7)
Body mass index, mean (SD), kgm^{-2}	21.88 (1.86)
Leg dominance - right, n (%)	18 (85.7)
History of past lower quadrant injury but has recovered (> 6 months), n (%)	
Nil	7 (33.3)
1 area	11 (52.4)
2 areas	3 (14.3)
Non-problem side clamshell strength, mean (SD), N	
0° hip flexion	196.6 (75.3)
30° hip flexion	190.6 (71.0)
60° hip flexion	172.6 (66.0)
90° hip flexion	170.5 (64.6)
Non-problem side muscle activity, mean (SD), %MVIC	
Gluteus maximus:	
0° hip flexion	52.37 (35.84)
30° hip flexion	64.10 (35.37)
60° hip flexion	83.92 (53.82)
90° hip flexion	100.73 (82.94)
Gluteus medius:	
0° hip flexion	108.68 (53.50)
30° hip flexion	120.07 (44.57)
60° hip flexion	130.47 (53.94)
90° hip flexion	135.22 (80.50)
Tensor fascia latae:	
0° hip flexion	93.98 (46.26)
30° hip flexion	89.37 (43.49)
60° hip flexion	75.89 (46.93)
90° hip flexion	80.94 (51.43)

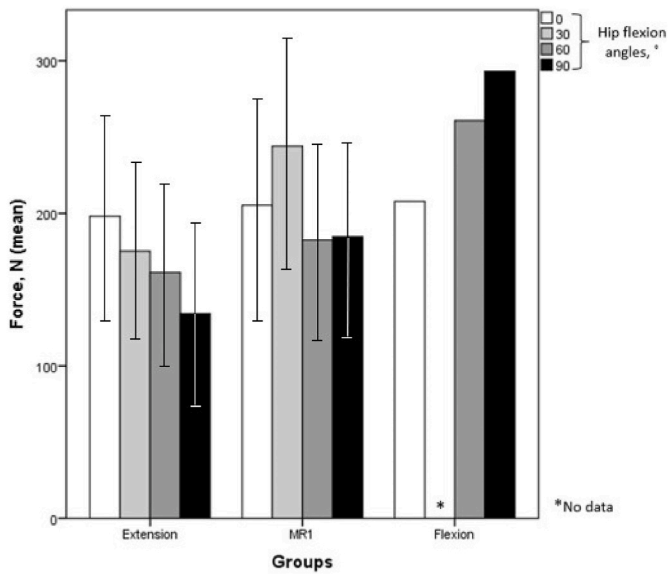

Fig. 4. Hip flexion angle strength trend categorised by directional preference and error bars representing means and standard deviations.

Table 2
Problem side strength and muscle activities grouped by directional preference.

Measurements, mean (SD)	Group		
	Extension (n = 12)	MR1 (n = 8)	Flexion (n = 1)
Clamshell strength, N			
0° hip flexion	198.0 (63.3)	205.2 (73.2)	207.9
30° hip flexion	175.2 (59.4)	244.1 (81.2)	[a]
60° hip flexion	161.2 (63.7)	182.5 (63.8)	260.9
90° hip flexion	134.2 (57.6)	184.6 (68.3)	293.2
GMax activity, %MVIC			
0° hip flexion	45.50 (26.57)	50.27 (19.06)	46.60
30° hip flexion	55.42 (42.12)	58.64 (18.43)	44.70
60° hip flexion	61.86 (42.75)	65.57 (32.03)	50.88
90° hip flexion	57.32 (35.07)	81.99 (38.12)	54.09
GMed activity, %MVIC			
0° hip flexion	110.58 (42.03)	83.16 (18.90)	81.97
30° hip flexion	107.11 (34.95)	93.28 (32.66)	93.61
60° hip flexion	113.25 (42.55)	88.08 (22.32)	125.32
90° hip flexion	110.08 (56.19)	106.17 (33.66)	111.13
TFL activity, %MVIC			
0° hip flexion	97.18 (62.44)	86.22 (42.54)	134.54
30° hip flexion	86.22 (42.54)	108.69 (80.64)	83.88
60° hip flexion	81.32 (40.18)	76.14 (43.21)	105.61
90° hip flexion	71.18 (44.37)	74.39 (52.00)	81.80

MR1: Preference in 30° hip flexion angle.
Gmax: Gluteus maximus; Gmed: Gluteus medius; TFL: Tensor fascia latae.
[a] Measurement error, no data.

group, there was a trend of decreasing force produced with increasing hip flexion angle. In contrast, the force trend was opposite for the flexion preference participant. The MR1 group showed a trend of lower force production with increasing hip flexion angles above 30°.

3.3. GMax, GMed and TFL muscle activities

The muscle activities of the non-problem side (0°, 30°, 60° and 90° hip flexion angles) are presented in Table 1, while the problem side is presented in Table 2. For the non-problem side, GMax activation was significantly higher in 90° hip flexion as compared to 0° and 30° hip flexion, %MVIC mean differences, are 47.10, 95% CI 7.81 to 86.40, $p = 0.021$ and 35.52, 95% CI 3.99 to 67.05, $p = 0.029$. Although the GMed activation showed similar incremental trend with increasing hip flexion angle as GMax, the changes were not significant. In contrast with the gluteal muscles, the TFL activation showed a gentle decline in activation with increasing hip flexion angles that was not significant between hip flexion angles.

For the problem side, there was no significant effect of hip flexion angles on muscle activities in the extension preference and MR1 groups. That said, the MR1 group showed similar GMax and GMed trend with the non-problem side, but not from the extension preference group. A potential dysfunction in the MR1 group could be excessive TFL activity, whereas those with extension preference could experience motor coordination impairments in the gluteal muscles. On the other hand, the flexion preference participant showed a lack of differentiation in GMax activity across the hip flexion angles.

3.4. Relationship between clamshell strength and muscle activities

In the non-problem side, clamshell strength at 0° hip flexion was positively and moderately correlated with GMax muscle activity, $r = 0.5$, $p < 0.05$. Other correlation analyses did not reach significance. In the 3-factor regression analyses (Table 3a), GMax activity was approximately predictive of clamshell isometric strength at 0° hip flexion, 1.15 unit (%MVIC) increase per 1 N force exerted, 95% CI -0.09 to 2.38, $p = 0.066$, while TFL activity was predictive of clamshell isometric strength at 90° hip flexion, 0.65 unit (%MVIC) increase per 1 N force exerted, 95% CI 0.08 to 1.22, $p = 0.029$. At 0° hip flexion, follow-up 2-factor regression analyses showed that GMax activity was predictive of clamshell isometric strength, 1.11–1.19 unit (%MVIC) increase per 1 N force exerted, $p < 0.05$, see Table 3b.

In the problem side, the regression analyses varied from the non-problem side and the results are presented in Table 3b. The 3-factor regression models were not significant at 0°, 30° and 90° hip flexion, whereas GMed and TFL were approximately predictive of clamshell isometric strength at 60° hip flexion, 0.79 unit (%MVIC) reduction per 1 N force exerted, 95% CI −1.62 to 0.03, $p = 0.059$ and 0.71 unit (%MVIC) increase per 1 N force exerted, 95% CI −0.03 to 1.45, $p = 0.059$ respectively. The follow-up 2-factor regression analyses showed that in the model of 60° hip flexion with GMed and TFL as predictors, GMed was predictive of clamshell isometric strength, 0.89 unit (%MVIC) reduction per 1 N force exerted, 95% CI −1.69 to −0.09, $p = 0.031$, while TFL remained approximately predictive of clamshell isometric strength, 0.7 unit (%MVIC) increase per 1 N force exerted, 95% CI −0.04 to 1.44, $p = 0.061$. Because of the abnormality of GMed in the problem side at 60° hip flexion, a comparison against the non-problem side was performed, which found GMed activity lower on the problem side, mean difference (SD) was 26.2 (56.1), $p = 0.045$.

4. Discussion

This is the first study investigating the clamshell exercise used in Clinical Pilates assessment for lateral bias. The study aimed to explore the influence of directional preference on clamshell strength and muscle activities in relatively healthy individuals – no history of injury or considerably recovered from past injuries for at least six months. All participants presented with a lateral bias (anteroposterior axis of trunk/hip movement) and flexion/extension bias (transverse axis of trunk/hip movement) was present in most participants (62%). The HHD could be used to discriminate subtle strength difference of clamshell exercise performed in different hip flexion angles among relatively healthy individuals, which could assist with the classification of directional preference in Clinical Pilates assessment. Apart from directional preference, the differing trends of strength and muscle activation between the problem and non-problem sides suggest that in a simple clamshell exercise, motor coordination of multiple muscles is essential and cannot be sufficiently explained by GMax, GMed and TFL alone, especially in the problem side. Past studies support the possibility of motor coordination

Table 3a
Peak muscle activities predicting strength (3-factor model).

Hip flexion angles/ muscles	%MVIC change per 1 N force increase	95% CI	*p*-value
Non-problem side			
0°			
GMax	1.15	−0.09 to 2.38	0.066
GMed	0.05	−0.77 to 0.86	0.91
TFL	−0.47	−1.24 to 0.31	0.22
30°			
GMax	0.01	−1.27 to 1.28	0.99
GMed	0.16	−0.73 to 1.05	0.70
TFL	−0.24	−1.14 to 0.66	0.58
60°			
GMax	−0.11	−0.78 to 0.57	0.74
GMed	0.03	−0.62 to 0.68	0.92
TFL	0.14	−0.64 to 0.91	0.72
90°			
GMax	−0.23	−0.75 to 0.28	0.35
GMed	−0.12	−0.64 to 0.40	0.64
TFL	0.65	0.08 to 1.22	0.029
Problem side			
0°			
GMax	0.05	−1.26 to 1.36	0.94
GMed	−0.23	−1.10 to 0.64	0.58
TFL	−0.02	−0.63 to 0.59	0.95
30°			
GMax	−0.48	−1.66 to 0.70	0.40
GMed	−0.59	−1.78 to 0.60	0.31
TFL	0.58	−0.06 to 1.23	0.074
60°			
GMax	−0.37	−1.13 to 0.39	0.32
GMed	−0.79	−1.62 to 0.03	0.059
TFL	0.71	−0.03 to 1.45	0.059
90°			
GMax	−0.19	−1.10 to 0.73	0.67
GMed	−0.65	−1.61 to 0.30	0.16
TFL	0.65	−0.18 to 1.48	0.11

Gmax: Gluteus maximus; Gmed: Gluteus medius; TFL: Tensor fascia latae.

Table 3b
Peak muscle activities predicting strength (2-factor model).

Hip flexion angles/ muscles	%MVIC change per 1 N force increase	95% CI	*p*-value
Non-problem side (0°) Model 1			
GMax	1.11	0.01 to 2.22	0.049
GMed	−0.07	−0.81 to 0.67	0.84
Model 2			
GMax	1.19	0.24 to 2.15	0.018
TFL	−0.45	−1.17 to 0.27	0.20
Model 3			
GMed	0.50	−0.20 to 1.20	0.15
TFL	−0.47	−1.31 to 0.36	0.25
Problem side (60°) Model 1			
GMax	−0.36	−1.18 to 0.47	0.37
GMed	−0.51	−1.34 to 0.32	0.22
Model 2			
GMax	−0.55	−1.34 to 0.25	0.17
TFL	0.45	−0.29 to 1.20	0.22
Model 3			
GMed	−0.89	−1.69 to −0.09	0.031
TFL	0.70	−0.04 to 1.44	0.061

Gmax: Gluteus maximus; Gmed: Gluteus medius; TFL: Tensor fascia latae.

impairment even after recovery from injury, which can lead to reduced strength and muscle activation of adjacent muscles (Bourne et al., 2016; Stevens et al., 2006). So, the use of non-problem and problem sides in our statistical analyses provide clinically relevant information as compared to categorisation by leg dominance, which is not always the problem side.

The difference in clamshell strength between varying hip flexion angles in the extension preference and MR1 groups support the use of clamshell exercise as an assessment in Clinical Pilates practice. A study suggested that the clamshell exercise could be used to assess directional preference in the anteroposterior axis of movement (Kwok et al., 2021), which is assessed using manual muscle testing to determine the strength of hip abduction. To understand the Clinical Pilates method, our study sought to explore the relationship of muscle activity with strength. In the non-problem side, this study only found an association between the clamshell isometric strength with GMax activity at the 0° hip flexion angle. The lack of association between strength and muscle activity is unsurprising. A study of people with lower strength found higher activation of muscles among them (Homan et al., 2013), which is more motor units of a muscle will be activated to compensate for a weaker force generated. In our study, the inclusion of a larger proportion of people who have recovered from injury could have led to meaningful clinical implication, which is injury recovery could result from muscle activity adaptation that deviates from the norm. Thus, it is possible that the Clinical Pilates method that focuses on the strength of the participant, supports proper conditioning of GMed when its activation is moderated, ie. neither the peak nor least activated.

In terms of muscle activity changes with increasing hip flexion angle, the non-problem side showed increasing GMax and GMed activities and decreasing TFL activity. Our findings are aligned with the findings of past studies (Boren et al., 2011; Distefano et al., 2009; Willcox and Burden, 2013). In addition, the 2-factor regression analyses showed that increase in GMax activation was associated with higher force at 0° hip flexion, whereas the 3-factor regression analyses showed that reduction of TFL activation at 90° hip flexion was associated with higher force. The trend could be explained by the functional anatomy of muscles and their corresponding force and torque production. Studies have shown that movement torque varies with body position, which is influenced by muscle force and moment arm (Hoy et al., 1990; Neumann, 2010). Positional changes potentially affect the line of force, resulting in decreased length of the moment arm and sometimes change the movement action of the muscle. As such muscle activities vary at different hip flexion angles. On the other hand, the problem side showed abnormality of the GMed muscle, specifically at 60° hip flexion, whereby its reduction was associated with increased strength, which is indicative of compensation from other muscles. GMed muscle activity was found to be the best in 60° hip flexion (Willcox and Burden, 2013), so our study findings of the problem side is supported with significant dysfunction of the GMed at this angle.

The varying muscle activity trends on the problem side suggest that impairments in the clamshell movement could be multi-factorial. Furthermore, the regression analyses showed differences in muscle activity as compared to the non-problem side at all angles of hip flexion. The findings illustrate that an exercise such as clamshell, rehabilitation is not specific to a muscle but rather a synchronisation of several muscles to achieve optimal motor coordination for force production. While motor control plays a potential role in protecting the back (Meier et al., 2019), recognising directional preference in exercise prescription can optimise the rehabilitation plan and minimise detrimental exercise prescription (Tulloch et al., 2012). For rehabilitation that desires targeted GMax, GMed or TFL activation, the movements used in MVIC testing positions are recommended (Selkowitz et al., 2013). That said, daily routine movements are not limited to single plane movement, so exercises such as the clamshell movement, which is a combination of hip abduction and external rotation with varying degrees of hip flexion, could allow for interference between muscles to promote motor coordination.

There are a few limitations in our study. Despite meeting the calculated sample size, the study sample was limited in distribution in the MR2 (60° hip flexion angle preference) and flexion groups. It is unfortunate that the study participant recruitment was affected by the pandemic. Although the study was limited in distribution, the isometric strength trends of the other 2 groups provide preliminary validation of the Clinical Pilates method in using the clamshell exercise to assess for lateral movement directional preference. Second, the study was limited to young adults during the pandemic and thus generalising the findings to older population will require consideration. Third, a standardised testing position that starts with 0° hip flexion angle favours people with extension directional preference, which would have favoured half of our study population. Thus, testing their problem side in the testing order (0° hip flexion angle first) might have diminished the difference from other angles that would have significantly poorer performance if latter angles were tested first. Future studies could consider testing position that starts with the least favourable condition, ie. position that is opposite to the directional preference.

5. Conclusion

In summary, the study showed that directional preferences were present in healthy individuals and those who have recovered from injuries, when tested with the clamshell testing of the Clinical Pilates method. Muscle activation patterns of the problem side differed from the non-problem side, specifically the GMed at 60° hip flexion. The non-problem side findings of muscle activation were aligned with existing literature that studied healthy population. In view of potential latent motor coordination impairment among relatively healthy individuals, DMA Clinical Pilates assessment such as the clamshell exercise could be used to screen individuals who intend to participate in multi-directional general exercise programme such as yoga, pilates and calisthenics. The study findings offer insights to how different individuals respond to general exercises, where some may acquire injuries but not others. Therefore, it is useful for practitioners to recognise favourable movement directions to facilitate exercise programme development and progression.

Authors' contribution

EAYYL was primarily responsible for the project conceptualization, drafting of the manuscript, data collection and data analyses.

RYTY was involved in the data collection of the project and review of the drafted manuscript.

BCK assisted in conceptualization of the project, project supervision, revision of the drafted manuscript and data analyses.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbmt.2023.04.091.

Abbreviations

DMA	Dance Medicine Australia
EMG	Electromyography
GMax	Gluteus maximus
GMed	Gluteus medius
HHD	Handheld dynamometer
MVIC	Maximal voluntary isometric contraction
TFL:	Tensor fascia latae
%MVIC	Ratio of maximal voluntary isometric contraction

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