[RESEARCH REPORT]

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DMA Clinical Pilates Directional-Bias Assessment: Reliability and Predictive Validity

SUPPLEMENTAL VIDEO ONLINE

STUDY DESIGN: Randomized, repeated-measures crossover design.

OBJECTIVES: To determine the interrater reliability of directional-bias assessment and to investigate its validity for predicting immediate changes in dynamic postural stability and muscle performance following directionally biased exercises.

BACKGROUND: Directional bias in dynamic postural stability deficits may be associated with outcome following intervention.

METHODS: Two researchers independently assessed 33 participants, each with a history of more than 1 unilateral lower-limb injury, for directional bias. Interrater reliability was evaluated with the kappa coefficient and a prevalence-adjusted and bias-adjusted kappa coefficient. Participants were randomly allocated to perform matched-bias (MB) or unmatched-bias (UB) exercises first, in 2 crossover groups. Two outcome measures, time to stabilization and rebound hopping, were assessed before and following each exercise intervention, using a force plate. Crossover trial data were analyzed by t tests for period, interaction, and treatment effects, and repeated-measures analyses of variance were used to investigate differences between baseline, MB, and UB.

RESULTS: Interrater reliability of directional-bias assessment was substantial ($\kappa = 0.75$; prevalence-adjusted and bias-adjusted $\kappa = 0.76$). Following MB exercises, medial/lateral time to stabilization and time on the ground during rebound hopping were significantly shorter ($P = .01$ and $P = .05$, respectively) compared with UB exercises. Compared with baseline, pairwise change in anterior/posterior time to stabilization ($P = .008$) improved following MB, whereas time in the air decreased following UB ($P = .036$).

CONCLUSION: Directional-bias assessment demonstrates substantial reliability, and outcomes suggest validity for predicting immediate improvements following matched directionally biased exercises. *J Orthop Sports Phys Ther 2012;42(8):676-687. doi:10.2519/jospt.2012.3790*

KEY WORDS: *dance medicine, exercise therapy, rehabilitation*

Pilates exercises have become very popular with the fitness industry and sports participants as part of core training programs. Physical therapists have incorporated them into rehabilitation programs as specific clinical, sport-specific, and general exercises. These exercises aim to strengthen and/or stretch muscle groups, to re-educate faulty movement patterns,[3,9,36] and to improve spinal stability as part of low back pain management.[15,26,45] Pilates exercises have been shown to activate and strengthen pelvic floor muscles[10] and to improve both static and dynamic balance in older adults[24]; however, a recent systematic review reported that Pilates-based exercise was no more effective at relieving pain and disability in individuals with persistent nonspecific low back pain than other forms of exercise.[27]

Dance Medicine Australia (DMA) Clinical Pilates is a new approach developed by Australian physical therapist Craig Phillips, Director of DMA Clinical Pilates.[38] DMA Clinical Pilates is used with the intent to correct dynamic postural stability deficits that may have resulted from injury. Phillips has adapted the traditional Pilates exercise approach[39] based on his experience as a professional ballet dancer and his subsequent physical therapy clinical experience, incorporat-

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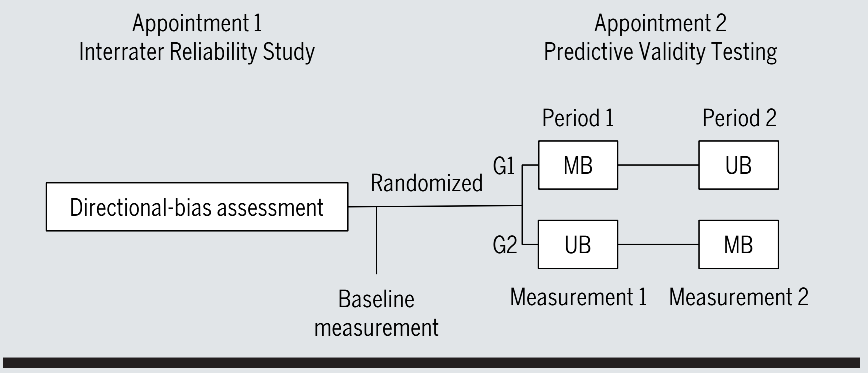

FIGURE 1. Flow chart of study design. G1, MB exercises followed by UB exercises; G2, UB exercises followed by MB exercises. Abbreviations: G1, group 1; G2, group 2; MB, matched bias; UB, unmatched bias.

ing evidence from spinal stability research.[6,17,19,20] Central to the DMA Clinical Pilates approach is the identification of a "directional bias" that identifies dynamic postural stability deficits.

Directional bias is determined via a clinical assessment process (**ONLINE VIDEO**, **ONLINE APPENDIX**). Directional bias has elements in common with "directional preference," a term used in the McKenzie method to describe a repeated end-range movement in a single direction or a sustained posture that abolishes or centralizes pain.[34] Patients given exercises matched to their directional preference have been shown to have significant and rapid reduction in pain compared to when exercising in the opposite direction.[28] Similarly, in the DMA Clinical Pilates approach, patients are rehabilitated with individual-specific, directionally biased exercises that are matched to observed dynamic postural stability deficits, referred to as "matched-bias" (MB) exercises. Hypothetically, performing MB exercises may result in immediate increases in performance, whereas performing exercises biased in the incorrect direction, referred to as "unmatched-bias" (UB) exercises, may result in decreased performance. To distinguish this concept from the McKenzie pain-centralization phenomenon of directional preference, we use the term "directional bias" with regard to differences in muscle performance and dynamic postural stability associated with movement direction in 2 planes: sagittal (flexion or extension) and lateral (left or right). This concept is based on clinical observations and has not previously been validated.

The developer of DMA, Craig Phillips, anecdotally reports observing immediate, within-session improvements in muscle performance and dynamic postural stability following performance of matched directionally biased exercises. Although these concepts are currently used by some physical therapists clinically, there is currently no scientific evidence that such directional-bias assessment can identify dynamic postural stability deficits and is reliable, or that immediate changes occur following MB or UB exercise.

Therefore, the aims of this study were (1) to determine the interrater reliability of the directional-bias assessment and (2) to investigate the predictive validity of the directional-bias assessment by testing the immediate effects of directionally biased exercises on physical performance of (*a*) dynamic postural stability and (*b*) rebound hopping in participants with previous unilateral lower-limb injuries.

For interrater reliability, our hypothesis was that agreement would exceed a kappa value of 0.60, indicating substantial agreement.[25]

For predictive validity testing, we hypothesized that (1) directional-bias assessment would predict the outcome of the exercise intervention, where participants who perform an individual-specfic MB unilateral exercise will perform better in (a) dynamic postural stability and (b) motor performance than those performing an UB exercise, and (2) MB exercise would result in an immediate improvement from baseline in (*a*) dynamic postural stability and (*b*) motor performance. Conversely, hypothesis 2 predicted that exercising in the opposite direction (UB) would result in immediate decreases in dynamic postural stability and performance from baseline.

METHODS

Participants

Participants who had experienced more than 1 musculoskeletal injury (soft tissue or bony injury) in 1 lower limb were recruited from the local university and polytechnic staff and student community. Exclusion criteria ruled out participants who reported any of the following affecting the lower limbs: injuries within the last 6 weeks, surgery in the last 6 months, fractures in the last 12 months, known arthritic conditions or inability to take body weight through arms, currently receiving physical therapy treatment for any injuries, current neurological or low back disorders, impairments that may affect postural stability, and known systemic conditions. Participants were screened via an online questionnaire and again at the first appointment. Ethical approval for this study was granted by the Lower South Regional Ethics Committee. All participants provided informed consent to their participation.

Design Overview

Participant flow through the study is described in **FIGURE 1**. Participants attended 2 appointments: (1) assessment of directional bias and (2) predictive validity testing.

Assessment of Directional Bias

Assessment of directional bias was conducted independently, in separate rooms, by the principal investigator (E.T.) and the expert advisor (C.P.). Both assessors

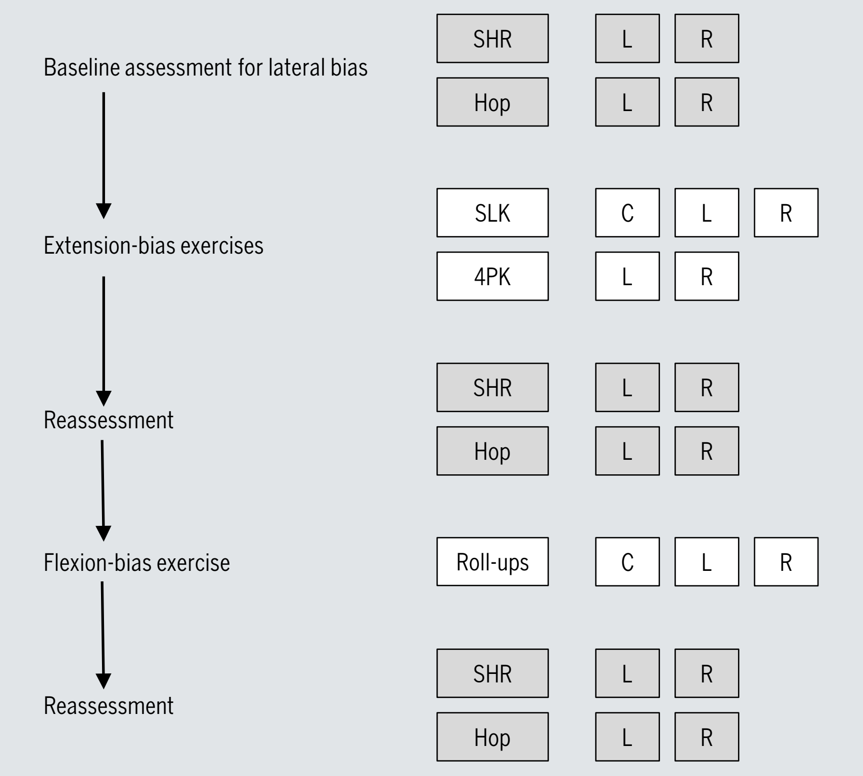

FIGURE 2. Flow chart of directional-bias assessment procedure. Abbreviations: 4PK, 4-point kneel; C, center; L, left; R, right; SHR, single-heel raise; SLK, single-leg kick.

were experienced musculoskeletal physical therapists. C.P. had additional experience with professional athletes and, in particular, the dance community. He was very familiar with the traditional form of Pilates and subsequently developed DMA Clinical Pilates. E.T. had no previous Pilates experience before completing the DMA Clinical Pilates training, which involved 4 levels, totaling 64 hours. No other specific training was provided to the assessors. Both followed an assessor procedure protocol and a participant instruction protocol developed by E.T.

Randomization For the predictive validity testing component of the study, a third investigator (G.S.) used an integer-generator website (http://www.random.org) to randomly allocate participants to the order of the exercise intervention (MB or UB conducted first), as well as the lower extremity to be tested first during the time-to-stabilization (TTS) and rebound-hop (RH) tasks. For blinding purposes, C.P.'s bias assessment results were used for randomization following the assessment of directional bias. Allocation was concealed in individual, sealed envelopes and opened by E.T. at the second appointment. Both the investigators present at predictive validity testing (E.T. and A.C.) and the participants were blinded to group allocation.[12]

Directional-Bias Assessment Description The directional-bias assessment (**FIGURE 2**, **ONLINE VIDEO**, **ONLINE APPENDIX**) was based on DMA Clinical Pilates principles and included 2 parts: a lateral (right, left) and a sagittal (flexion, extension) bias. A lateral bias was defined as the observation of more movement (ie, less stability) of the trunk and/or pelvis, or greater effort perceived by the participant or observed by the physical therapist, on 1 side (left or right) compared to the other side during execution of specific exercises. Sagittal (flexion or extension) bias was defined as increased ability to execute and control specific exercises with the spine placed in a flexed or extended position, resulting in better performance during reassessment (**ONLINE VIDEO**). A directional bias was therefore made up of 2 components. The better-performing flexion or extension bias was used to improve the poorer-performing side (lateral bias).

In this study, lateral bias was established using baseline observation during 1 set of 5 single-heel raises and hops on each leg, to establish the poorer performing of the left or right side (**FIGURE 2**, **ONLINE VIDEO**, **ONLINE APPENDIX**). The single-heel raise and hop exercises were used for reassessment following extension and flexion-bias exercises.

To assess sagittal bias, participants performed extension-bias exercises with lumbar lordosis (3 sets of 10 single-leg kick and 4-point kneel exercises on each leg) and flexion-bias exercises with spinal flexion (up to 3 sets of 5 repeated roll-ups) (**FIGURE 2**, **ONLINE VIDEO**, **ONLINE APPENDIX**). Roll-ups were stopped if the participant's form deteriorated or the participant was unable to continue.

Single-leg kicks and roll-ups were performed first in midline, then 1 set with legs to the left and 1 set with legs to the right, to confirm lateral bias (**FIGURE 2**, **ONLINE VIDEO**, **ONLINE APPENDIX**), that is, whether the left or right side was deficient (increased movement or effort observed). Lateral bias was confirmed when the side (eg, right) that had increased movement or effort in midline produced improved performance with the legs taken to the ipsilateral (right) side and produced poorer performance with the legs taken to the contralateral (left) side, away from the poorer-performing side.

The matched lateral bias was the side with the poorer-performing single-heel raise and hop, and with the greater movement observed in the lumbar spine while the participant was performing single-leg kick and 4-point kneel, along with greater lateral weight transference toward the poorer-performing side during the 4-point kneel (**ONLINE VIDEO**). The matched flexion or extension bias was determined by the spinal position (flexion or extension) in which the participant had better control and better performance during reassessment of single-heel-raise and hopping exercises (**FIGURE 2, ONLINE VIDEO**). The participant's directional bias was thus categorized as flexion right, flexion left, extension right, or extension left. These results from each assessor (E.T. and C.P.) were put into appropriately marked, separate, sealed envelopes. C.P.'s directional-bias assessment results were used for the predictive validity testing component of the research. For blinding purposes, the reliability study was conducted following the completion of the predictive validity testing component. A third investigator (G.S.) stored E.T.'s results until required for use in the reliability study.

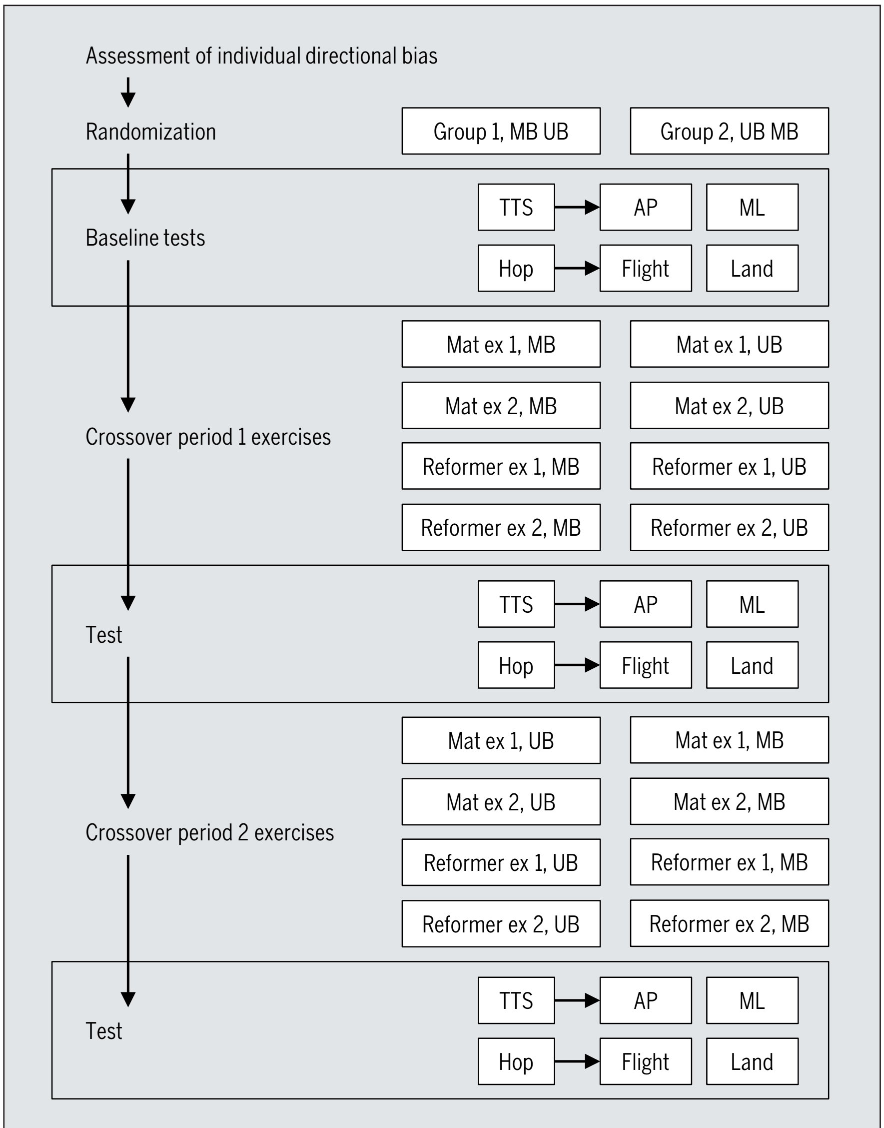

FIGURE 3. Flow chart of the predictive validity testing procedure. Group 1, MB exercises followed by UB exercises. Group 2, UB exercises followed by MB exercises. Flight is the median time in the air during 5 rebound hops, and land is the median time on the ground during 5 rebound hops. Period 1, first set of 4 exercises; period 2, second set of 4 exercises. Abbreviations: AP, anterior/posterior; Ex, exercise; Hop, rebound hop; MB, matched bias; ML, medial/lateral; TTS, time to stabilization; UB, unmatched bias.

Outcome Measures

Force Plate Data Collection Two force plates (Advanced Mechanical Technology, Inc, Watertown, MA), recessed flush with the floor of the Biomechanics Laboratory (University of Otago), were used to collect 3-D ground reaction force (GRF) data at a sampling rate of 1000 Hz during TTS and RH testing. An external USB analog-to-digital converter (NI USB-6218; National Instruments, Austin, TX) and data collection software (Cortex Version 1.1.4; Motion Analysis Corporation, Santa Rosa, CA) were used to collect GRF data. The force data from both force plates were added together to derive total GRF. Total GRF was used in subsequent calculations.

TTS Force Plate Data Collection Dynamic postural stability was assessed independently in the horizontal anterior/posterior (AP) and medial/lateral (ML) planes using TTS.[43] We obtained the TTS stability threshold according to the "horizontal range-of-variation line," as described by Ross and Guskiewicz.[43] AP TTS was calculated by smoothing the raw GRF data with a moving root-mean-square 250-point window, with the smoothed line staying below the stability threshold for at least 500 samples (0.5 second). To determine ML TTS, the raw GRF data were smoothed with a moving root-mean-square 500-point window, with the smoothed line staying below the stability threshold for at least 500 samples (0.5 second). The 2 baseline TTS trials were used to obtain the stability threshold.[43] The average of the 2 stability thresholds in the respective ML and AP directions from the baseline measures was applied to each of the corresponding MB and UB conditions. By applying the same baseline stability threshold to both MB and UB conditions, we reasoned that a truer indication of the participant's dynamic postural stability would be achieved, because our hypothesis was that the stability threshold would differ following the 2 conditions.

Rebound Hop Force Plate Data Collection Rebound hop was used as a measure of muscle performance, with time in the air (height hopped) indicating power, whereas time on the ground was taken as a measure of dynamic postural stability, coordination, and control to the next take-off. The median values for both time in the air and time on the ground, obtained from 5 continuous hops, were used in the analysis.

TABLE 1 PARTICIPANT DEMOGRAPHICS*

	Men (n = 16)	Women (n = 17)	All (n = 33)
Age, y	28.0 ± 11.0	27.0 ± 8.9	27.0 ± 9.8
Height, cm	179.0 ± 7.8	168.4 ± 7.2	173.7 ± 9.2
Weight, kg	83.5 ± 18.0	78.0 ± 14.3	80.7 ± 16.2
Body mass index, kg/m^2	25.8 ± 4.2	27.3 ± 5.3	26.6 ± 4.8

**Values are mean ± SD.*

Predictive Validity Testing Procedures

After the procedures (**FIGURE 3**) were explained to the participants, they were familiarized with the equipment and exercises (**ONLINE VIDEO**, **ONLINE APPENDIX**). Participants were informed that a video camera would record their tests. However, if consent to filming was declined, the video was turned off. Video recordings were used to help determine the successful completion of test procedures.

TTS testing was carried out as previously described by Ross and Guskiewicz,[43] with participants performing a 2-footed jump from 50% to 55% of maximum jump height and landing on the designated leg. Participants were barefoot in this study (**ONLINE VIDEO**). One successful practice trial (a trial consisted of 1 two-footed jump) and 2 test trials were performed on each leg, with up to 1 minute of rest between trials. Unsuccessful trials were repeated, with a maximum of 6 trials on any 1 side before this test was deemed too difficult and abandoned.

Rebound hop testing was adapted from Petschnig et al[37] (**ONLINE VIDEO**). Participants were instructed to stand on their test leg, with their hands on their hips, looking at a mark on the wall, and to "hop as high and rhythmically as possible, keeping contact with the force plate for as short a time as possible, as if it were a hot plate," for 5 hops. One practice trial and 1 test trial were performed, with up to 1 minute of rest between each trial. A trial was repeated if the nontest foot touched the ground, participants hopped off the force plate, or took their hands off their hips. This procedure was repeated on the other leg.

Predictive Validity Testing Exercises Left and right flexion-bias exercises consisted of 2 DMA Clinical Pilates mat exercises (spine stretch and single-leg stretch) and 2 DMA Clinical Pilates reformer exercises (stomach pull flat and stomach massage) (**ONLINE VIDEO**). Left or right extension-bias exercises consisted of single-leg kick and 4-point kneel exercises performed on a mat, with only the leg for that bias (left or right) exercised, and knee stretch and cat stretch performed on the reformer biased by placing the hands to the left or right on the bar (**ONLINE VIDEO**). More detailed description of the predictive validity testing exercises can be accessed in the **ONLINE APPENDIX**. Each exercise was performed for 4 minutes, in a sequence of 1 minute of exercise and 15 seconds of rest, resulting in a total of 16 minutes of exercise, excluding rests, in each crossover period.

Crossover Period 1 Testing According to random allocation, the 4 MB or UB exercises were performed. Prior to each exercise, E.T. demonstrated and the participant practiced the exercise. TTS and RH testing followed completion of period 1 validity-testing exercises.

Crossover Period 2 Testing The opposite-condition exercises (MB or UB) were performed, in accordance with group allocation, followed by TTS and RH testing.

Data Analysis

Aim 1: Interrater Reliability of the Directional-Bias Assessment Results were compared using the kappa coefficient (κ = [observed agreement – chance agreement]/[1 – change agreement]) and the prevalence-adjusted and bias-adjusted kappa (PABAK) coefficient. Byrt et al[5] proposed the PABAK to overcome a substantial decrease in the kappa value in categories with low prevalence.

$$\text{PABAK} = \frac{\left(\frac{2n}{N}\right) - 0.5}{1 - 0.5} = 2p_o - 1$$

Aim 2: Predictive Validity Predictive validity testing data analyses were performed using the Analysis Toolpak add-in in Excel 2003 (Microsoft Corporation, Redmond, WA) and the SPSS Version 16 (SPSS Inc, Chicago, IL) statistical software package. The level of statistical significance was set at P<.05. A 1-sample Kolmogorov-Smirnov test in SPSS was used to confirm normal distributions of the raw data, and the force platform data were screened for outlier values.

Aim 2: Hypothesis 1 It has been noted by a number of authors[2,11,18] that it is incorrect to analyze data from a crossover trial by a simple comparison of treatments, as if it were a typical matched-pair design. We have used the sequence of analyses recommended by Altman[2] for analyzing crossover trials to investigate differences in outcomes between the MB and UB exercises. The Altman[2] method involves testing for period effect, treatment-period interactions (carryover from 1 period to the other), and treatment effect. Period effects and treatment-period interactions were tested for by using a 2-tailed, 2-sample t test, assuming unequal variance, on the AP and ML TTS and the median values of the 5 RHs. Time in the air and time on the ground were both analyzed for RH. However, in crossover trials, t tests for treatment-period interactions are noted for lack

TABLE 2 Number of Participants With a History of Injury by Type and Location of Injuries*

Types of injury, n*	Injured region, n
Fracture, 6	Hip, 7
Dislocation/subluxation, 5	Groin, 2
Muscle tear, 1	Thigh, 24
Tendon rupture, 1	Knee, 76
Ligament rupture, 38	Lower leg, 6
Lesion of meniscus, 8	Achilles tendon, 2
Sprain, 56	Ankle, 56
Strain, 39	Foot, 8
Bursitis, 2	Total, 181
Tendonitis, 5	
Other, 20	
Total, 181	

Numbers sum to greater than 33 because all participants had history of more than 1 injury.

of statistical power.[18] Thus, graphs, as suggested by Hills and Armitage,[18] were used to identify treatment-period interactions and to determine any association between a treatment-period interaction and treatment response. Hypothesis 1 requires treatment effect (predictive validity) to be unidirectional; therefore, this was tested using a 1-tailed *t* test of the mean MB and UB TTS values and the median values of time in the air and time on the ground in both the AP and ML directions.[2,40] To help demonstrate any treatment-period interaction, *t* tests of the mean MB and UB TTS values in period 1 were calculated separately from period 2 values. If results were different, this could be interpreted as the influence of the period 1 treatment on the period 2 treatment.

Aim 2: Hypothesis 2 If hypothesis 1 was accepted, the next important step for further research was to determine whether MB and UB exercise would result in an immediate significant improvement or decrement from baseline measures, respectively. The analysis of results for such a study would use repeated-measures analyses of variance with pairwise comparison. We collected baseline measurements as pilot data to inform future sample-size estimations. Hypothesis 2 is, therefore, exploratory in nature, with low power. For hypothesis 2, an analysis of variance F test was used to test for differences in TTS between baseline, MB, and UB conditions for both AP and ML directions and time on the ground and time in the air for RH. The TTS variables compared were the mean and variance in TTS and were compared for the 3 TTS conditions in the AP and ML directions. The median values of time in the air and time on the ground were compared for the RH conditions. As hypothesis 2 is a secondary, exploratory investigation, we made no adjustments for multiple comparisons.

Sample size was calculated for the primary outcome of treatment effect in hypothesis 1. We estimated that to achieve power of 0.8 to detect a 15% difference in TTS in a crossover design, with alpha set at $P<.05$, a sample size of 35 participants was required.[43,49]

To determine whether participants were able to perform the TTS task with greater consistency under the MB condition than under the UB condition, the variance of the 2 MB and UB tests was compared via a *t* test. This was repeated for both the AP and ML directions.

Repeatability of TTS testing was tested by following the Bland and Altman[4] method. TTS was calculated from the average of the 2 TTS tests. Thus, average measured intraclass correlation coefficients ($ICC_{2,2}$) from baseline, MB, and UB conditions were calculated as a second measure of repeatability to enable comparison with other TTS studies.

Standard error of measurement represents the standard deviation of the measurement errors. This was used to compare with other TTS studies that have reported standard error of measurement.

RESULTS

We recruited 33 participants (17 women, 16 men; mean ± SD age, 27.0 ± 9.8 years; range, 18-48 years) (**TABLE 1**). The types of injuries reported and their body regions are displayed in **TABLE 2**. All participants had an identifiable lateral and sagittal bias.

Aim 1: Interrater Reliability

Descriptive data of the 2 assessors are presented in **TABLE 3**. Agreement between the assessors was achieved for 27 of 33 participants (82%). The interrater reliability was $\kappa = 0.75$ and PABAK = 0.76, indicating substantial agreement.[25]

Aim 2: Results of Predictive Validity Testing

All participants agreed to be videotaped and all performed both exercise conditions (MB and UB). A complete set of data was obtained for the RH test; however, 9 participants were unable to perform a successful TTS test. A technical error occurred in recording GRF in 1 TTS trial for 1 participant. For another participant, the MB TTS value was considered an outlier in the Fy component (ML direction), while in another the Fx component for UB was considered an outlier. These values were quite distinct from all other TTS values and judged unlikely to be a true representation of the participant's performance. Thus, those data were excluded from analysis, with all other data for these participants retained.

Aim 2: Hypothesis 1

TTS Period Effects and Treatment-Period

TABLE 3 COMPARISON OF ASSESSMENT OF DIRECTIONAL BIAS BY 2 RATERS

		Rater 2				
		Flexion Left	Flexion Right	Extension Left	Extension Right	Total
Rater 1	Flexion left	9	0	0	0	9
	Flexion right	1	11	0	1	13
	Extension left	3	0	1	1	5
	Extension right	0	0	0	6	6
	Total	13	11	1	8	33

TABLE 4 SUMMARY OF PERIOD EFFECT AND TREATMENT-PERIOD INTERACTION FOR TTS AND REBOUND HOP

	t Statistic	2-Tailed *P* Value
TTS		
Period effect, AP TTS	0.35	.73
Period effect, ML TTS	−0.28	.78
Treatment-period interaction, AP TTS	−1.31	.21
Treatment-period interaction, ML TTS	−1.55	.13
Rebound hop		
Period effect, flight*	−0.14	.89
Period effect, land†	−1.14	.27
Treatment-period interaction, flight*	0.11	.91
Treatment-period interaction, land†	1.16	.25

Abbreviations: AP, anterior/posterior; ML, medial/lateral; TTS, time to stabilization.
**Median time in the air between 5 rebound hops.*
†Median time on the ground between 5 rebound hops.

Interactions No statistically significant period effects or treatment-period interactions were found (**TABLE 4**). However, treatment-period interactions (carryover of effects of exercise in period 1 into period 2) can be observed in **FIGURE 4** for TTS, as the mean responses do not coincide (the lines did not cross each other in the middle) (**FIGURES 4A** and **4B**).[2,18] Absence of treatment-period interaction would be indicated by the distance between MB and UB in period 1 being the same as that in period 2. Post hoc *t* test analyses for TTS in periods 1 and 2 further revealed the influence of exercises in period 1 carrying over into period 2 (**TABLE 5**).

TTS Treatment Effect (Predictive Validity) Superior performance in the MB condition compared with the UB condition would satisfy hypothesis 1, that the directional-bias assessment would predict the outcome of exercise intervention. Raw data are presented in **TABLE 6**. A significant decrease of 13.4% was observed in ML TTS, indicating that following MB exercise participants took significantly less time to stabilize (better) compared to UB exercise, as predicted by hypothesis 1 (**TABLE 7**). A decrease was also observed in the AP direction for TTS following MB exercise compared to UB exercise; however, the difference (8.0%) was not statistically significant (**TABLE 7**). A statistically significant decrease in variance (P = .004) was found for MB when compared to UB in ML TTS, with no significant difference found for AP TTS. However, when period 1 data were analyzed separately, to separate the influence of carryover effects in period 2, the mean ML TTS with MB was 26.9% better than with UB exercise, and the 17.7% improvement found in AP TTS was also statistically significant (**TABLES 5** and **7**).

Rebound Hop Period Effects and Treatment-Period Interactions No statistically significant period effects or treatment-period interactions were found (**TABLE 4**); however, **FIGURE 4** indicates the presence of treatment-period interactions. Both **FIGURES 4C** and **4D** indicate carryover effects from period 1.

Rebound Hop Treatment Effect (Predictive Validity) Superior performance in the MB condition compared with the UB condition would satisfy hypothesis 1, that the directional-bias assessment would predict the outcome of exercise intervention. Raw data are presented in **TABLE 6**. A treatment effect in flight response following MB exercises can be observed. Means and standard deviations for time in the air and time on the ground are displayed in **TABLE 7**. Participants took significantly less time to stabilize (time on the ground) following MB exercises compared with UB exercises. However, this did not meet the clinically important difference of 15%.

Aim 2: Hypothesis 2

Within-participant effects were found to be significantly different (P = .049) in AP TTS but not in ML TTS (P = .114). A significant difference in variance (P = .035) was found between conditions in ML TTS, but no significant differences were found in AP TTS. Within-participant effects during RH were better, with time on the ground significantly decreased (P = .041) and time in the air significantly increased (P = .016) following MB exercises. For pairwise comparisons in AP TTS, MB was less (better) than baseline (P = .008), and significantly shorter time in the air (worse) followed UB exercises (P = .036), as predicted by hypothesis 2. However, no significant difference was observed between MB and UB. Post hoc testing revealed significant decreases in ML TTS variance following MB exercises compared with both baseline (P = .048) and UB exercises (P = .023). The standard errors of measurement of AP and ML TTS, for MB and UB conditions, are reported in **TABLE 8**.

TTS reliability repeatability coefficients and $ICC_{2,2}$ results for AP and ML TTS are reported in **TABLE 8**, along with $ICC_{2,1}$ results for RH.

DISCUSSION

THIS STUDY INVESTIGATED THE RELIability and predictive validity of a clinical directional-bias assessment to detect dynamic postural stability deficits. We found a substantial agreement between the 2 DMA Clinical Pilates–trained therapists to independently classify directional bias in participants' dynamic postural stability performance, and that identification of directional bias predicted the outcome of hypothetically matched versus unmatched exercise interventions. TTS was found to be significantly faster following MB exercise in the ML direction compared to UB exercise, whereas during RH, participants spent significantly less time on the ground between hops. Although the 0.47-second (13.4%) improvement in ML TTS did not meet our criteria for minimally important differences of 0.5 seconds or 15%, the lower bound of the 95% confidence interval (0.39 seconds, 11%) is comparable with mean improvements in postural stability following 6 weeks of postural stability exercises and elastic-band training (9.2% and 11.3%, respectively) reported in other studies.[13,41] Powers et al[41] found a decrease of 6% in center-of-pressure displacement values following 6 weeks of strength and proprioceptive training. The clinically meaningful results reported by those studies would suggest that our criteria for minimal clinical difference were reasonable and perhaps conservative. Further, the crossover design demonstrated that the effects of the first-period exercise influenced the effects of the second-period exercise (**TABLE 5**, **FIGURE 4**). When period 1 data were analyzed separately, eliminating interaction effects, a mean improvement of 1.01 seconds (26.9%) was found following the 16 minutes of exercise. This would suggest that following MB exercise, a clinically meaningful improvement may be obtained. AP TTS significantly decreased (better) following MB exercise, whereas motor power (time in the air) was significantly decreased (worse) following UB exercise, compared to baseline. Further investigation is required to determine if the immediate changes found in this study can be further improved with additional treatment sessions.

The directional-bias assessment achieved substantial agreement between the 2 DMA Clinical Pilates–trained ther-

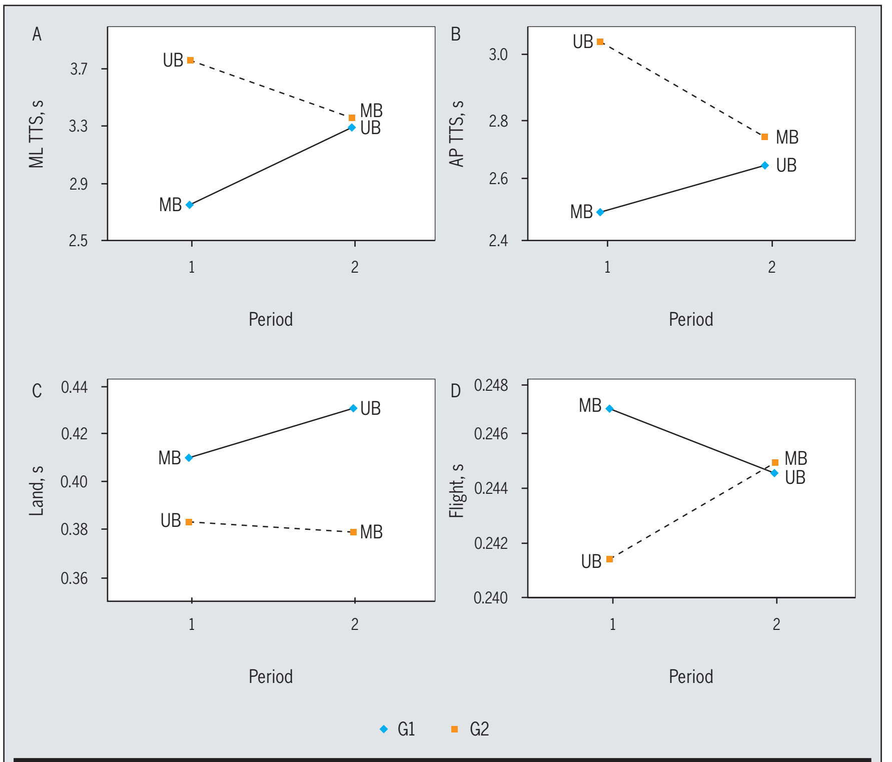

FIGURE 4. Graphical representation of treatment-period interaction in a crossover trial, as described by Hills and Armitage.[18] (A) ML TTS and (B) AP TTS outcomes during periods 1 and 2. Outcomes of the median values of 5 rebound hops for (C) time on the ground (land) and (D) time in the air (flight) for periods 1 and 2. G1, MB exercises followed by UB exercises; G2, UB exercises followed by MB exercises. Abbreviations: AP, anterior/posterior; G1, group 1; G2, group 2; MB, matched bias; ML, medial/lateral; TTS, time to stabilization; UB, unmatched bias.

TABLE 5 TIME TO STABILIZATION

	TTS Matched*	TTS Unmatched*	Difference†	*P* Value	Percentage Difference
Period 1					
AP	2.51 ± 0.65	3.05 ± 0.95	–0.54 (–0.97, –0.11)	.05	–17.7
ML	2.75 ± 0.85	3.76 ± 1.01	–1.01 (–1.55, –0.49)	.01	–26.9
Period 2					
AP	2.75 ± 0.51	2.66 ± 1.00	–0.09 (–0.49, 0.33)	.39	–3.40
ML	3.37 ± 0.90	3.30 ± 1.30	–0.07 (–0.42, 0.28)	.44	–2.12

Abbreviations: AP, anterior/posterior; ML, medial/lateral; TTS, time to stabilization.
**Values are mean ± SD seconds. Data demonstrate treatment in period 1 influencing treatment in period 2 for both TTS directions.*
†Values are mean (95% confidence interval) seconds.

apists.[25] Our result provides confidence that this directional-bias assessment can reliably identify deficits in dynamic postural stability in participants who have recovered from unilateral lower-limb injuries, and strengthens our confidence that directional bias exists as a valid clinical phenomenon. The present study was limited to 2 raters; therefore, a study with a larger sample of raters is required to be confident of high interrater reliability in classifying directional bias in a wider population of therapists. The assessment may be clinically applicable to patients during recovery from a lower-limb injury; however, this requires further inquiry. It is difficult to compare these results directly to other interrater reliability studies of subgrouping classifications within physical therapy, as the classification systems tested in other studies have generally investigated pain responses rather than dynamic postural stability.[7,14,42]

Clinically, other combinations of directional bias may be observed. However, for this initial study of directional bias, it was decided to make the categories as simple as possible. Clinically, there are key direction-related questions, the most common being the strong relationship between aggravating/easing factors and direction, and second being the direction of trauma/injury. Less common patterns include neutral/multidirectional/global instabilities, but they are beyond the scope of this paper, which addresses the most common clinical scenarios. In indeterminate cases, just as in the McKenzie method, patients may be asked to exercise in 1 direction periodically over 24 to 48 hours and then reassessed. Future study may encompass a broader range of patterns for better accuracy of directional-bias assessment.

Our results support hypothesis 1 in relation to predictive validity of the directional-bias assessment, particularly with respect to land time between hops and ML TTS. Our results also showed significantly less variability between the 2 ML TTS tests following MB exercises, indicating more consistent performance of dynamic postural stability. Although the repeated-measures analyses of variance for hypothesis 2 were underpowered, they demonstrated a consistent direction of results, several of which were statistically significant: improved dynamic stability following MB exercises and deteriorated height hopped following UB exercises. Our results are in agreement with findings in other (unrelated) assessment systems: that exercises matched to an individual's directional preference (directional bias) produced superior outcomes to those performed in the opposite direction.[28,29] Additionally, outcomes deteriorated when exercises were not matched to directional preference.[28,29] Thus, matched directionally biased exercises may improve performance

TABLE 6 Descriptive Data for Time to Stabilization and Rebound Hop Outcome Measures

	Mean ± SD, s	Skewness
Anterior/posterior TTS		
Baseline	3.13 ± 0.64	–0.46
Matched bias	2.69 ± 0.66	1.10
Unmatched bias	2.86 ± 0.98	1.52
Medial/lateral TTS		
Baseline	3.62 ± 1.27	0.72
Matched bias	3.05 ± 0.91	0.13
Unmatched bias	3.53 ± 1.15	1.44
Time in the air		
Baseline	0.27 ± 0.07	–0.11
Matched bias	0.25 ± 0.06	–0.03
Unmatched bias	0.24 ± 0.06	–0.10
Time on the ground		
Baseline	0.38 ± 0.11	1.23
Matched bias	0.40 ± 0.10	1.03
Unmatched bias	0.41 ± 0.11	1.15

Abbreviation: TTS, time to stabilization.

TABLE 7 Data for Time to Stabilization and Rebound Hop

	Matched*	Unmatched*	Difference†	*P* Value	Percentage Difference
Primary outcomes					
AP TTS	2.63 ± 0.58	2.86 ± 0.98	–0.23 (–0.11, 0.16)	.15	–8.0
ML TTS	3.05 ± 0.91	3.52 ± 1.17	–0.47 (–1.33, –0.39)	.02	–13.4
AP TTS‡	2.51 ± 0.65	3.05 ± 0.95	–0.54 (–0.97, –0.11)	.05	–17.7
ML TTS‡	2.75 ± 0.85	3.76 ± 1.01	–1.01 (–1.55, –0.49)	.01	–26.9
Secondary outcomes					
Hop, time in the air	0.25 ± 0.06	0.24 ± 0.06	0.003 (–0.004, 0.01)	.23	4.0
Hop, time on the ground	0.40 ± 0.09	0.41 ± 0.10	–0.013 (–0.015, –0.01)	.05	–3.3

Abbreviations: AP, anterior/posterior; ML, medial/lateral; TTS, time to stabilization.
**Values are mean ± SD seconds.*
†Values are mean (95% confidence intervals) seconds.
‡Values with treatment-period interaction eliminated.

TABLE 8 SUMMARY OF RELIABILITY DATA

Statistic/Condition	Anterior/Posterior, s	Medial/Lateral, s
Repeatability coefficient		
TTS baseline	3.76	4.10
TTS matched bias	2.94	2.92
TTS unmatched bias	4.27	3.84
SEM		
TTS matched bias	1.50	1.49
TTS unmatched bias	1.79	1.58
$ICC_{2,2}$ (95% CI)		
TTS	0.43 (–0.13, 0.73)	0.51 (0.05, 0.77)
$ICC_{2,1}$ (95% CI)		
Rebound hop	0.75 (0.60, 0.86)*	0.81 (0.70, 0.90)†

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; SEM, standard error of measurement; TTS, time to stabilization.
**Time in the air.*
†Time on the ground.

outcomes related to dynamic postural stability; however, further investigation is needed to confirm these findings.

The immediate differences in performance found in favor of MB exercises may result from alterations at the central nervous system level. Traditional rehabilitation to improve postural stability following a lower-limb injury requires 2 to 6 weeks of exercises to influence muscle physiology and motor learning[13,33,35]; however, the design of this study provided insufficient time for changes in muscle physiology to take effect, indicating that the mechanism is likely neurophysiologic in nature. The neural drive is strongly influenced by the afferent proprioceptive system,[23,33,35] affecting motor output from the central nervous system.[23,46] A possible explanation for the immediate improvements found could be that the proprioceptive information the central nervous system received from the MB exercises was facilitatory to motor output, resulting in more immediate improvements in muscle power and dynamic postural stability, whereas that received by UB exercises was inhibitory. Another possible mechanism is a learning effect, which has been proposed to show immediate improved performance within 1 session.[8,30,31]

The lack of a significant effect in the variables AP TTS and time in the air (hypothesis 1) might have been due to the presence of treatment-period interactions and low power. Although *t* test results did not confirm treatment-period interactions, they lack statistical power for that purpose,[2,18] and the presence of period effects cannot be ruled out.[11] The graphs, as suggested by Hills and Armitage,[18] did indicate the presence of treatment-period interactions, as the average response for each crossover group did not coincide. If there were no interaction, the rise in 1 condition would have been equal to the fall in the second condition in the second test period and the lines would have crossed in the middle of the graph. The graphs and the separate analysis of the 2 periods (**TABLE 5**) for TTS clearly demonstrate the interaction between exercise conditions (carryover from period 1, which might have been due to insufficient washout between the 2 exercise periods), reducing the difference between conditions by approximately 50%. In addition, 2 of the flexion-bias exercises were too challenging for many participants, which affected test performance and might have contributed to the nonsignificant results. Local trunk-stabilizing muscle activity is reduced when exercises are made more challenging, as has been shown during a curl-up exercise,[22] which involved similar muscle activity to the 2 difficult flexion-bias exercises in this study. As a result, TTS and RH values for flexion-bias exercises performed as part of MB exercises might have been poorer than expected, thus reducing any potential experimental effect. Twenty-two of the 33 participants had flexion as part of their MB. Future studies could minimize the chances of treatment-period interactions by (*a*) having a washout period and (*b*) using less-challenging flexion-bias exercises.

We found that data analysis of TTS, as described and applied by Ross and Guskiewicz,[43] returned some implausible results. We therefore tried several modified methods to overcome this problem. To find the most repeatable method of fitting a smoothed curve to the data to obtain a TTS value, we compared the TTS of 12 participants independently assessed by 4 researchers. We then validated the modified method of Ross and Guskiewicz[43] on the remaining 16 participants' baseline graphs, achieving a mean ± SD error of 0.17 ± 0.49 seconds. These challenges may be explained by the samples of young athletes from university student populations used by other studies of the TTS technique.[16,43,47] Such a population would be expected to be more able to perform the challenging TTS task, with less variability, than the participants in this study, who were all previously injured, barefooted, and varied more in age, weight, and fitness. In addition, previous studies have all been of a cross-sectional design, compared to the crossover design of this study. Thus, the differences in TTS would not be expected to be as great between MB and UB exercises as they would be when comparing injured to healthy, uninjured participants, as in the other studies. There are a variety of methods for the determination of TTS from GRF data across the different studies in the literature.[16,32,43,44] The number of TTS trials in previous studies has varied from

3 to 10 trials.[16,43,44] Although VanMeter[50] suggested that 3 practice trials may be sufficient in a population of healthy participants, significant fast motor-skills learning has been shown to occur for up to 6 trials, with improvements still occurring for all 10 repetitions,[31] suggesting that a minimum of 6 trials of TTS may be required. A truer indication of TTS or dynamic functional stability might have resulted from the selection of an easier task that was more appropriate for the abilities of the current participants and the use of a minimum of 6 trials. This would have resulted in less within-subject variability and diluted the effect of a poor trial. Although the errors in this study indicated a large variability, which may reflect our heterogeneous population, no other study is known to have included errors for TTS determination, so comparison is not possible. Poorer repeatability compared to that of previous studies may also have been due to our varied population and the low number of trials.[43,44,52] Other studies have reported ICC and standard error of measurement values; however, different methodologies were used in their calculations.[43,44,51] These issues require consideration in future research. Because of the low ICC values and large variability in this TTS task, we cannot recommend it as a clinical outcome measure for the purpose of assessing change over time in individual patients.

Similarly, the RH test might have been affected by the long intervention session (90 minutes) and thus contributed to the nonsignificant results. Petschnig et al[37] looked at 10 seconds of hopping in a younger, athletic participant population. Participants in our pilot testing found this difficult, so we reduced RH testing to 1 set of 5 hops. Our method, therefore, was less able to accommodate a participant landing badly during 1 of the hops, which might have affected the results disproportionately compared with those of Petschnig et al.[37] Notwithstanding these issues, our results show that dynamic postural stability (time on the ground) significantly improved following MB exercise, whereas strength and power (time in the air) were affected detrimentally following UB exercise during RH.

It has previously been reported that long-term postural stability deficits may remain for up to 42 years following injury.[1,21,48] Directional-bias assessment and exercise programs may have important implications for physical therapy rehabilitation. The results of this study support further study of directionally biased exercises in rehabilitation management programs for patients following lower-limb injury, as these results show superior outcomes with MB exercises and inferior results with the unmatched exercise bias. However, this initial study has focused on the predictive validity of the directional-bias assessment and cannot provide evidence of treatment effectiveness. It is possible that rehabilitation guided by directional-bias assessment may result in patients being rehabilitated more quickly, resulting in earlier return to work and/or sport (with improved and more consistent sporting performance). We therefore recommend that this be investigated in future research. We speculate that, in a patient group seeking clinical care, the immediate differences may be expected to be greater. Similarly, our results indicate that rehabilitation exercises applied in certain (unmatched) directions may be detrimental for some patients.

CONCLUSION

Results from this first study to investigate core principles of DMA Clinical Pilates indicate that assessment of directional bias is reliable, and that identification of a directional bias can predict the outcome of performing individual-specific MB exercises, resulting in immediate improvements in dynamic postural stability and performance. ◉

KEY POINTS

FINDINGS: Assessment of directional bias as described was reliable, and identification of a directional bias predicted the outcome of performing individual-specific MB exercises, resulting in immediate improvements in dynamic postural stability and performance.

IMPLICATIONS: These findings indicate the potential of this approach to be used in the treatment of individuals with residual deficits from a previous injury.

CAUTION: This initial investigation was conducted in a population of participants with a history of repeated lower-limb injuries, but not currently seeking care.

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APPENDIX

DIRECTIONAL-BIAS ASSESSMENT INSTRUCTION MANUAL

This instruction manual presents details for the directional-bias assessment, which consists of 2 assessment exercises used for baseline assessment and reassessments, 2 extension-bias exercises (with lumbar spine in extension) and 1 flexion-bias exercise (with lumbar spine in flexion). One extra extension-bias exercise, which participants performed when it was hard to differentiate whether they were an extension- or flexion-bias responder, is also described. The exercises are adopted from DMA Clinical Pilates course manuals.

DIRECTIONAL-BIAS ASSESSMENT

Baseline Assessment

Participants performed the following 2 exercises for baseline assessment measures to determine whether the participant's performance was superior on the left or right side.

1. Single-Heel Raise (SHR)

Participants were instructed to:

- Stand with feet together, then
- Stand on 1 leg, place their hands on top of the assessor's hands;
- Rise up on to their toes as high as possible;
- And return to the starting position;
- Repeat this 5 times on each leg.

The assessors monitored differences in the performance of SHRs on 1 leg compared to the other by:

1. Assessing possible differences in the weight/effort they could feel through the participant's hands;
2. Noting any differences in balance;
3. Noting any difference in height raised;
4. Noting any signs of fatigue during the 5 repetitions.

FIGURE 1. Single-heel raise.

2. Hopping

Participants were instructed to:

- Stand with feet together, then
- Stand on 1 leg, place their hands on top of the assessor's hands;
- Hop as high and rhythmically as they could, treating the ground like a hot plate;
- Repeat this for 5 hops on each leg.

The assessors:

1 Assessed any difference in the weight/effort they could feel through the participant's hands as they hopped;

2 How rhythmical the hop was;

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3 How high they hopped;
4 How large the surface area covered while hopping on 1 foot was compared to the other.

FIGURE 2. Hop.

Lateral Directional-Bias Assessment

Lateral bias was determined from the participant's performance during baseline assessment measures (the poorer-performing side) and was compared to whether the participant had a left- or right-sided bias during the performance of 3 mat intervention exercises, 2 with the lumbar spine in lordosis (extension bias) and 1 with the lumbar spine in flexion (flexion bias).

Extension Bias (With Lumbar Lordosis)

<u>Single-Leg Kick</u>

Participants were instructed to:

- Lie prone with their feet together, place their hands under their head;
- Bend their knee to 90°, draw their stomach up;
- Breathe in as they lift their knee only 5 cm off the floor;
- Breathe out as they straighten their knee and lower their leg to the floor;
- Repeat 10 times on each leg;
- Rest for 1 minute and repeat this sequence twice more.

The assessors observed for any:

1. Lumbar spine extension and/or rotation when the exercise was performed with one leg compared to the other;
2. More effort was required with one leg compared to the other;
3. Improvement or worsening in control of the lumbar spine with repetition.

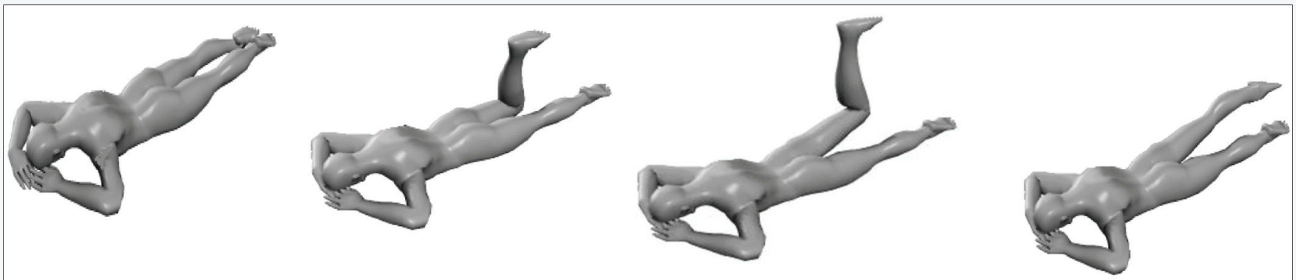

FIGURE 3. Single-leg kick.

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Retest Against Bias and Retest With Bias

Participants were then instructed to:

- Take both legs to the side where it was observed the participant had performed the exercise with more stability (against bias);
- Perform 1 set of repetitions in this position;
- Take both legs across to the other side (with bias);
- And perform another set of repetitions.

The assessors observed for any:

1. Change in the participant's control and or effort to perform the exercise in these 2 positions compared to the mid position.

FIGURE 4. Directional-bias assessment showing the right side with less stability and the mid, against-bias, and with-bias positions during a single-leg kick exercise.

Four-Point Kneel

Participants were instructed to:

- Get onto their hands and knees, place their hands together directly under their shoulders and their knees together directly under their hips, set scapulae in mid position, and have their lumbar spine in a normal lordosis;
- Keep their hips square as they breathe in and extend their leg out so it is parallel to the floor;
- Breathe out as they bring their knee into their chest while maintaining a lordosis (disassociating hip flexion from lumbar flexion);
- Return to the starting position;
- Repeat 10 times on each leg;
- After 1 minute of rest, repeat this sequence twice more.

The assessors observed for:

1. The amount of lateral movement of the pelvis;
2. Loss of lumbar extension and/or rotation control, comparing 1 side with the other. Following 1 minute of rest, this sequence was repeated twice more.

APPENDIX

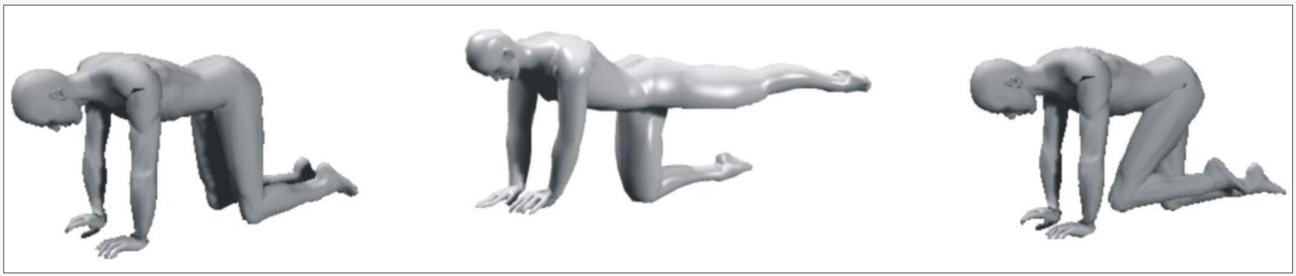

FIGURE 5. Four-point kneel.

Reassessment

From the single-leg kick and 4-point kneel intervention exercises, the assessors confirmed whether the left or right side was deficient (increased movement observed). A reassessment of both the SHR and hop was performed. It was determined whether, compared to the baseline measure, the participant performed the SHR and hop with:

1. More or less stability;
2. More or less weight was felt through the assessor's hands;
3. Rose higher or lower onto toes or hopped higher or less high;
4. Fatigued any more or less quickly.

The lateral (left or right) bias result was then compared to the participant's history of injury from the injury profile form. Through clinical observation, the lateral bias tends to match the side of the injury.

Flexion Bias (With Lumbar Flexion)

The participant was then tested for response to flexion bias. This was done by observing their performance during repeated roll-ups. Participants were asked to repeat this exercise 5 times.

1. Roll-ups

Participants were instructed to:

- Lie supine, with feet together and with their arms overhead and their scapulae down;
- Flex their shoulders to 90°;
- Take a mid-range breath in as they flex their spine segmentally and roll up into a long sitting position;
- Segmentally roll down to supine;
- Repeat 5 times.

After a short rest (up to 1 minute), they were asked to repeat 5 more roll-ups, unless their performance deteriorated. If they were still performing this exercise correctly, the sequence was repeated.

If the participant:

1. Was unable to perform this exercise;
2. Or found repeating 5 was too difficult;
3. Or their ability to perform this exercise correctly and smoothly was deteriorating, they were asked to stop and perform the roll-down part of the exercise instead.

Participants were classed as flexion-bias responders if:

1. They were able to perform either version of this exercise easily with good control;
2. They could not perform 5 repetitions, but were able to improve with each set.

APPENDIX

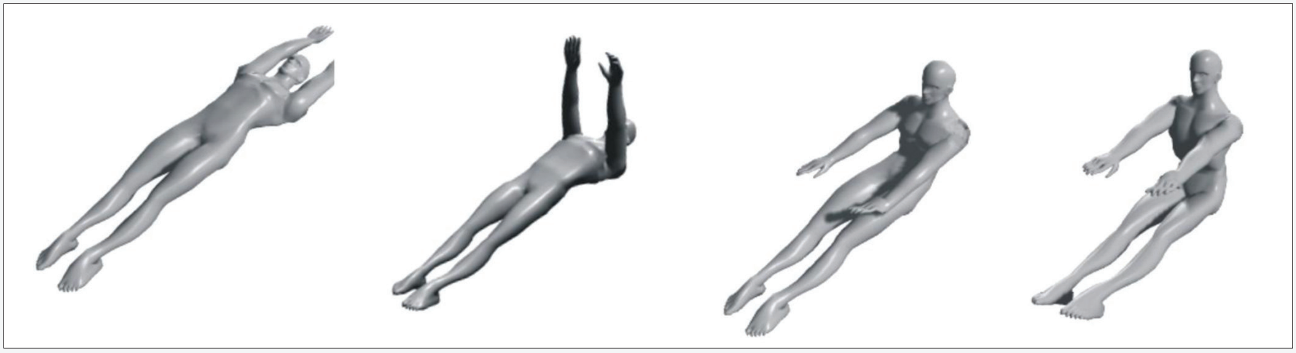

FIGURE 6. Roll-ups.

If the participants could not perform either version of the exercise or if their performance was deteriorating with repetition, they were deemed to be an extension-bias responder.
To help confirm a left or right lateral bias, both legs were taken to the better performing side (against bias), as determined from the above assessment, and the participant was asked to perform a set of roll-ups or roll-downs. They were then asked to take their legs across to the other side and repeat the exercise for another set (with bias). Any difference in performance was then noted between the 2 sides and the mid position.

Reassessment
The SHR and hop tests were performed as above and any difference in the participant's performance was noted. If the participant was deemed to respond to a flexion bias, these reassessment tests were performed with:
1 Better postural stability;
2 Less fatigue toward the end of the hops or SHRs;
3 Less weight felt through the assessor's hands;
4 The participant was able to hop higher or rise higher onto their toes;
5 A smaller surface area was covered while hopping.

These parameters helped to confirm they were a flexion-bias responder. If the reassessment tests (SHR and hop) were found to have deteriorated and the participant found the exercise of roll-ups difficult or their form had deteriorated with repetition, this contributed toward confirming they responded to an extension bias.
If it was difficult to determine whether they had a flexion or extension bias, 1 set of 10 repetitions of a double-leg exercise was added.

Double-Leg Kick
Participants were asked to:
- Lie prone with their feet together, hands under their head, and with their thoracic spine in slight extension;
- Bend their knees to 90°;
- Breathe in as they lift their thighs off the floor;
- Breathe out as they extend their arms and legs long and low, keeping their shoulders down and their abdominals lifted;
- Return to starting position;
- Repeat 10 times.

After this exercise, a further reassessment was performed as above. The biases for flexion and extension were compared to the question asking whether the participant preferred sitting or standing for long periods of time.

APPENDIX

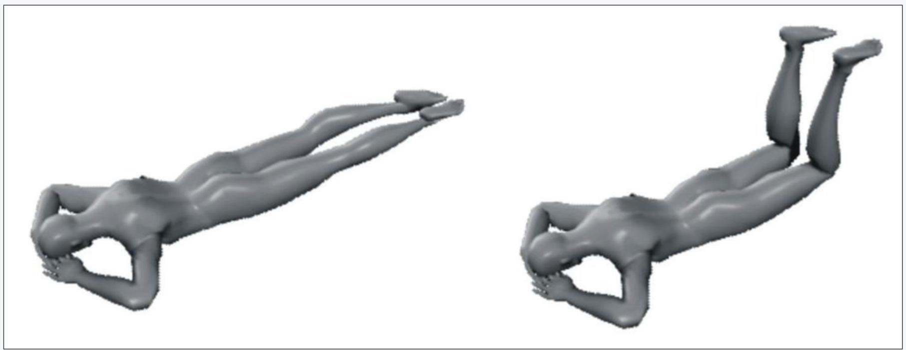

FIGURE 7. Double-leg kick.

Classification of Directional-Bias Assessment

These biases are made up of 2 parts: a left or right lateral bias and a flexion or extension bias. The matched lateral bias was the side that was deemed to be deficient and required improved control. That is, there was more movement observed in the lumbar spine while the participant was performing the single-leg kick exercise and lateral pelvis movement and/or lumbar movement during the 4-point kneel exercise. The flexion or extension matched bias was the direction in which the participant had the better control, with a resulting better performance of the SHR and hop. Thus, the participant-specific flexion or extension bias that was associated with improved performance was used to improve the lateral deficiency. The unmatched bias was opposite to the matched bias.

INSTRUCTION MANUAL FOR EXERCISES USED IN THE PREDICTIVE VALIDITY TESTING STUDY

This instruction manual presents details and instructions for the predictive validity testing exercises, which consisted of: 2 mat and 2 reformer exercises with the lumbar spine in flexion and 2 mat and 2 reformer exercises with the lumbar spine in extension. All exercises are adapted from DMA Clinical Pilates course manuals.

PREDICTIVE VALIDITY TESTING EXERCISES

All exercises were performed for 1 minute, followed with a 15-second rest. This sequence was repeated until a total of 4 minutes of the exercise had been performed.

Exercises for Left or Right Flexion Bias

Two mat and 2 reformer exercises were chosen to demonstrate how different types of exercise regimes can be adapted to biasing.

<u>Single-Leg Stretch</u>

Participants were instructed to:

- Lie on their back with both knees bent up to their chest;
- Place their (left or right) hand on the outside of the ankle of their nonexercising leg and the inside hand on the inside of the knee on the same side;
- Breathe in as they straighten their exercising leg out, no lower than 45°;
- Breathe out as they return their leg to the starting position.

The moving leg was the leg for the bias in this exercise. **FIGURE 8** demonstrates a right flexion bias. The participant's exercise leg was only extended out to 45° to maintain the posterior pelvic tilt.

APPENDIX

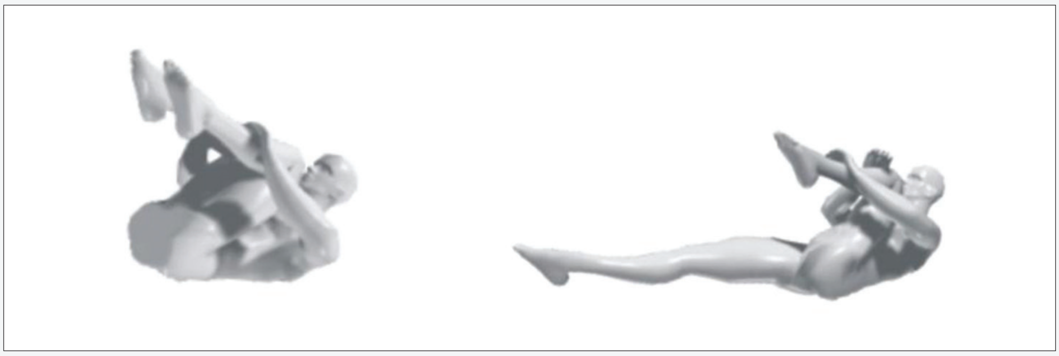

FIGURE 8. Single-leg stretch.

Spine Stretch

Participants were instructed to:

- Sit up onto their ischial tuberosities with their hips and knees flexed;
- Have their arms out in front or crossed across their chest;
- Rotate their trunk either to the left or to the right;
- Breathe in as they perform a posterior pelvic tilt, segmentally flex through their lumbosacral spine through midrange flexion, and roll back while keeping their shoulder girdle down;
- Breathe out as they return to starting position.

The spine stretch was made with a left or right bias by having the trunk rotated to the left or the right.

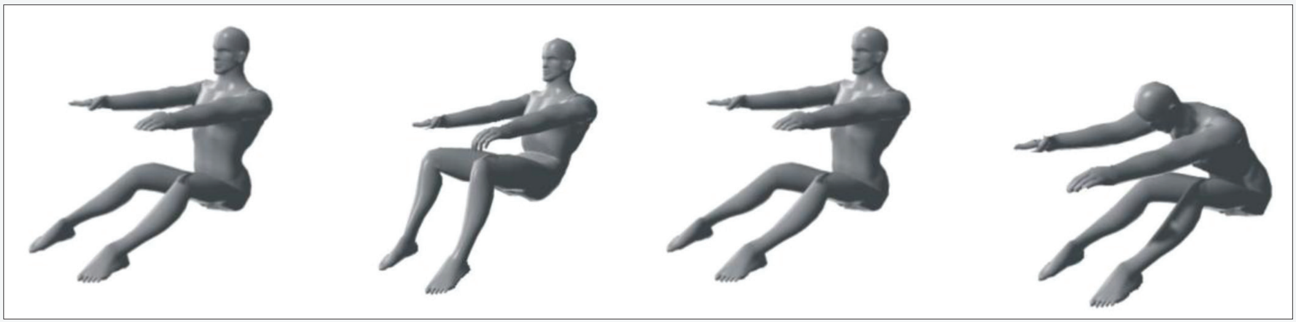

FIGURE 9. Spine stretch.

The following 2 exercises were performed on the reformer. Spring setting 2M refers to the setting of 2 springs in mid-position (**FIGURE 10**). There is a choice of 3 settings for the springs. 2H refers to 2 springs set in the hardest position (**FIGURE 11**). That is the setting where the springs are stretched the most in the resting position.

Stomach-Pull Flat

Participants were instructed to:

- Place both feet flat on the carriage with heels against the shoulder pads, with their knees straight or, if unable, then slightly bent;
- Place both hands to the left or to the right along the bar;
- Stretch their shoulders out fully;
- Breathe in as they push the carriage back-straightening hips, keeping their feet flat;
- Breathe out as they bring the carriage back to the starting position.

To make this exercise have a left or right bias, both of the participant's hands were placed either to the right or to the left on the bar.

APPENDIX

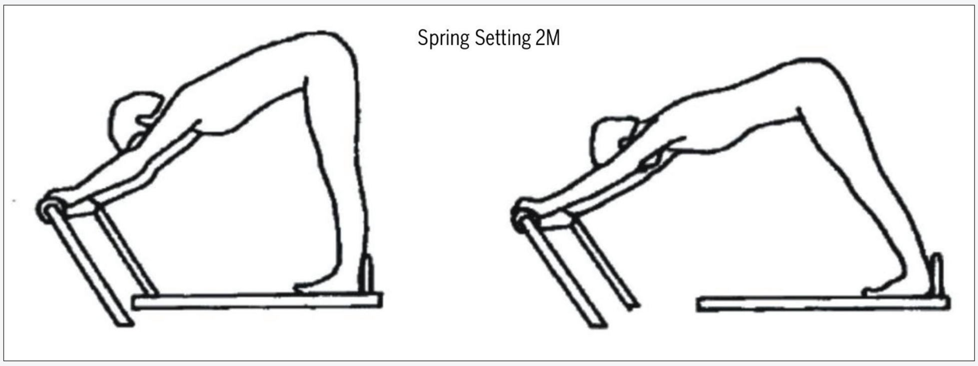

FIGURE 10. Stomach-pull flat.

<u>Stomach Massage</u>
Participants were instructed to:
- Place their feet to the left or right on the bar, have their hips bent up and parallel;
- Tip their pelvis back;
- Have their arms crossed across their chest;
- Rotate their trunk to the left or to the right;
- Keep their shoulders down;
- Breathe in as they straighten their knees fully, while keeping their pelvis tilted back;
- Breathe out as they return to the starting position.

Stomach massage was made with a right or left bias by having the trunk rotated to the left or right either with arms crossed or out in front. If participants found this exercise too tiring, they were able to rest their hand, on the same side as they were rotated to, on the carriage behind them.

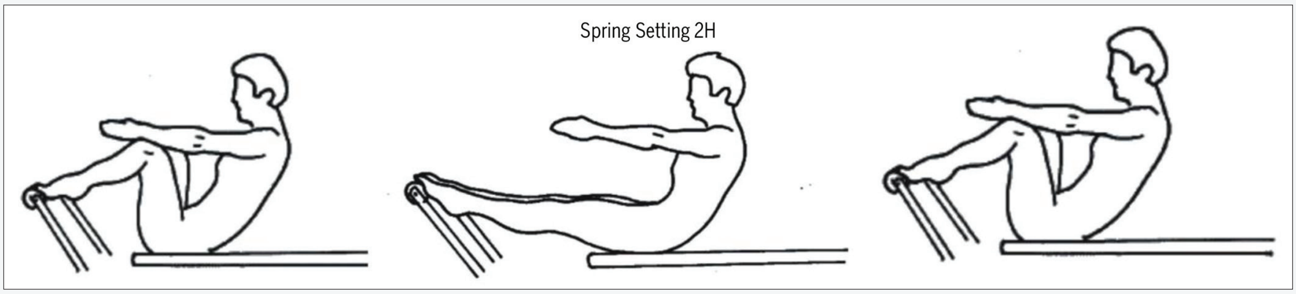

FIGURE 11. Stomach massage.

Exercises for Left or Right Extension Bias
Two mat and 2 reformer exercises were chosen to demonstrate how different types of exercise regimes can be adapted to biasing. All exercises were performed for a total of 4 minutes each using the same procedure of exercising and resting as described above.
The following 2 exercises were performed on a mat. Only the leg for that bias (left or right) was exercised.

<u>Single-Leg Kick</u>
Participants were instructed to:
- Lie prone with their feet together, placing their hands under their head;
- Bend their knee to 90°;
- Breathe in as they lift their knee only 5 cm off the floor;
- Breathe out as they straighten their knee and lower their leg to the floor.

APPENDIX

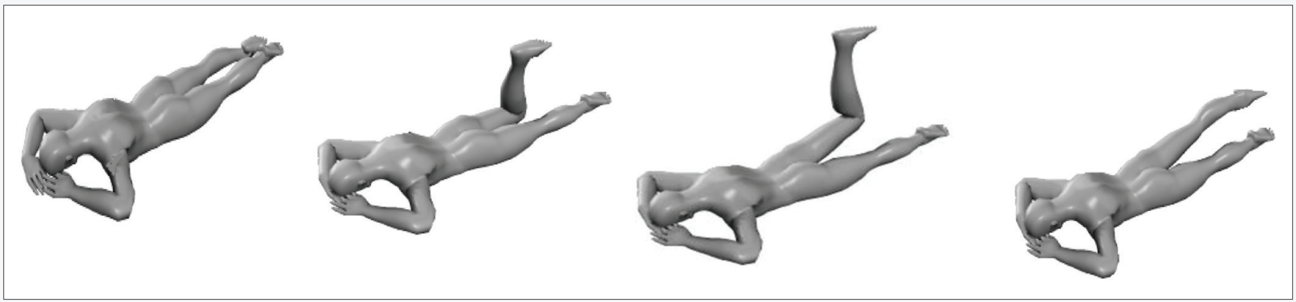

FIGURE 12. Single-leg kick.

Four-Point Kneel

Participants were instructed to:

- Get onto their hands and knees, place their hands together directly under their shoulders and their knees together directly under their hips, set scapulae in mid position, and bring their lumbar spine in a midrange lordosis;
- Keep their hips square as they breathe in and extend their leg out so it is parallel to the floor;
- Breathe out as they bring their knee into their chest while maintaining a lordosis, disassociating hip flexion from lumbar flexion;
- Return to the starting position.

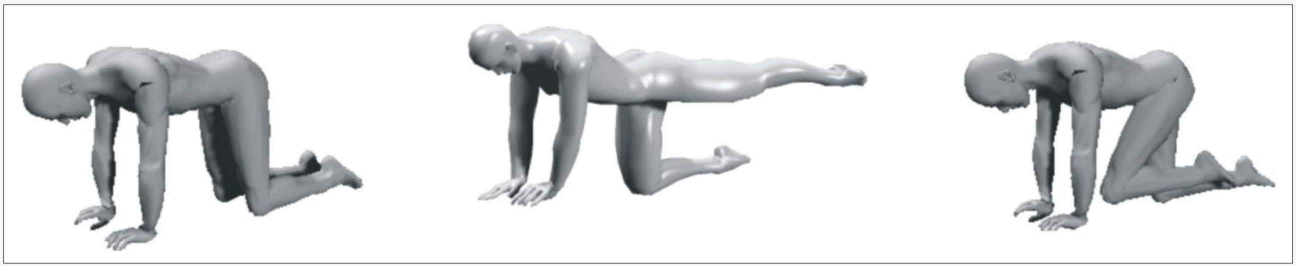

FIGURE 13. Four-point kneel.

The following 2 reformer exercises were performed.

Knee Stretch

Participants were instructed to:

- Place their feet on the pads and sit on their heels;
- Place their hands to the left or right;
- Push carriage back with their shoulders until arms are at 90°;
- Keep their shoulder blades down and their arms at 90° through the exercise;
- Breathe in as they straighten their hips through a small range and out as they bend their hips while bringing the carriage back in through a small range.

To bias this exercise both hands were placed to the right or left along the bar.

APPENDIX

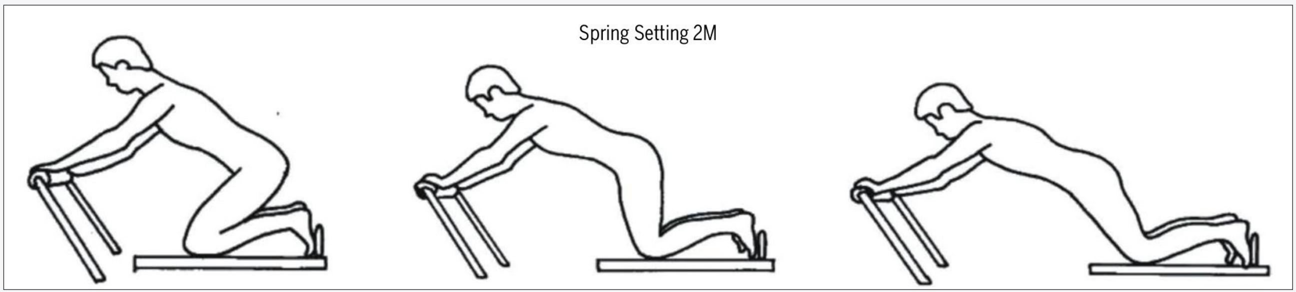

FIGURE 14. Knee stretch.

Cat Stretch

Participants were instructed to:

- Lie on the reformer with their legs between the shoulder pad supports and their pelvic bones on the edge of the carriage;
- Place their hands to the left or right;
- Breathe in as they push the carriage back until their body is flat;
- Keep their arms straight and breathe out as they bring the carriage back in, extending their hips fully.

Hands were placed to the left or to the right along the bar for biasing left or right.

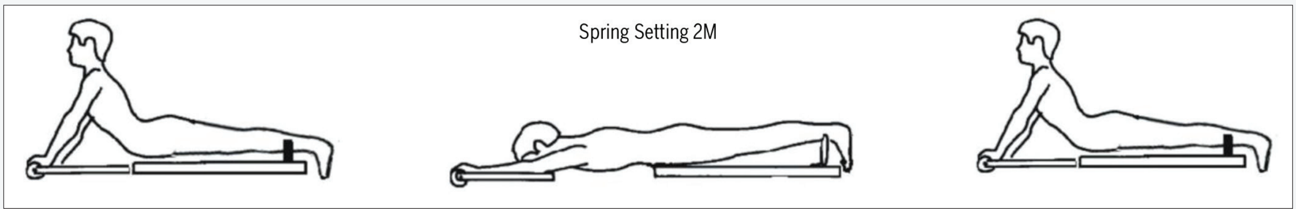

FIGURE 15. Cat stretch.