Sheffield Hallam University | Advanced Wellbeing Research Centre

An evaluation of the biomechanical, muscular and physiological responses to power assisted exercise amongst healthy older adults

'The Five Elements of Healthy Ageing' Report

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innerva
together in motion

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1. Background

Power Assisted Exercise (PAE) machines are accessible and feasible for use by people with complex impairment (Young et al 2018). The machines are designed to support the users in different positions whilst the machines assist movements of the trunk and limbs. Users are encouraged to generate physical energy whilst on the machines, however the energy generated has not been assessed or quantified in clinical studies. Innerva, Shapemaster Global Ltd, currently manufactures seated, seven recumbent and two Access Range machines. Each machine assists a variety of movement patterns to enable users to participate in a comprehensive exercise programme including bimanual and bilateral movements.

The integration of PAE machines with published exercise guidelines has been suggested to represent an accessible, evidence-based exercise intervention suitable for people with complex motor impairment (Young et al, 2018). Inclusion of the wider population of elderly people is yet to be tested. This study aimed to measure in real time the aerobic, muscular and kinetic demand and assess the physiological, postural and biomechanical responses during PAE amongst older adults to better understand the potential of this form of exercise to optimise physical well-being.

Jacobson et al (2012) hypothesised that PAE machines when used actively would generate both upper and lower body muscle endurance and improve body balance in a safe exercise environment. The efficacy of a twelve-week programme utilising PAE machines and incorporating only concentric contractions while trying to accelerate the moving levers was evaluated with the Berg Balance Scale and ability to perform muscular techniques including leg extension, bench press and triceps extension. The results detected improvement in balance and muscle endurance. However, the immediate aerobic, muscular and kinetic responses to PAE have not been measured and evaluated.

The components of fitness and physical performance which are central to sustained wellbeing amongst older adults are aerobic fitness, muscular strength, balance and flexibility. In addition, psychosocial status which is influenced by levels of physical activity and social interaction is very important.

Aerobic fitness reflects the capacity of the cardio-respiratory system, ie. the heart, lungs and blood vessels to deliver oxygen to exercising muscles. Aerobic fitness declines with age and people with very limited aerobic capacity experience breathlessness during every day activities

including walking short distances, performing household chores and stair climbing. Limited aerobic fitness can lead to social isolation as people avoid going out due to anxiety associated with breathlessness and physical fatigue. Aerobic fitness reduces the likelihood of developing heart disease, diabetes, high blood pressure and stroke. Aerobic exercise is an important component of successfully managing common long-term conditions including high blood pressure and diabetes.

Muscular capacity is an essential component of movement and mobility. Sarcopenia, a process through which muscular mass is depleted, is part of the ageing process. However, engagement in physical activity and resistance training decreases the rate of sarcopenia and active older adults retain more muscular mass than sedentary individuals. Reduced muscle mass is a predictor of frailty amongst older adults and associated with reduced physical resilience. Individuals with limited muscular capacity are at risk of falls, injury or health complications.

Balance is a complex component of functional movement which involves the relay of signals between the sensory and motor systems. Balance declines with older age due to slower reaction times, reduced strength and decreased flexibility. Reduced balance is a strong predictor of falls and subsequent morbidity amongst older adults. Exercise interventions which target muscular strength and movement sequences improve balance performance and enhance self-confidence.

Flexibility is a pre-requisite of everyday tasks including reaching, dressing and getting in and out vehicles. Flexibility declines with age as the elasticity of soft tissue decreases. This can lead to pain, stiffness and decreased independence. Repeated movement and stretches through the joints of the limbs and trunk improve the elasticity of the soft tissues and maintain or restore flexibility. Good flexibility is also associated with maintenance of good posture and balance reactions.

Aim

To measure in real time the aerobic, metabolic, muscular, postural and biomechanical responses to PAE on 11 different machines amongst a sample of healthy older adults.

Objectives

● To measure the aerobic and metabolic demand of PAE using Cardio Pulmonary Exercise Testing (CPET)
● To measure the muscular responses to PAE using EMG compared with Maximal Voluntary Contraction (MVC) of selected large muscle groups
● To measure the biomechanical and kinetic response to PAE using a 26 camera Motion Analysis System (MAS)
● To measure the effect of PAE on balance performance using a force plate to detect centre of pressure displacement before and after a session of PAE.

2. Methods

Ethical approval was gained through Sheffield Hallam University ethics committee, reference ER36907800

Participant recruitment

The inclusion criteria were;

- Adult aged between 55-80
- Able to wear vest and shorts
- Able to tolerate palpation and attachment of sensors to the skin
- Independently mobile with no significant movement impairment
- Able to interpret written and spoken English
- Able to give informed consent

The exclusion criteria were;

- History of neurological, respiratory or cardiovascular disease
- Persistent or severe musculoskeletal changes
- Persistent or severe pain
- Sensory impairment
- Cognitive impairment

A convenience sample of older adults were recruited through the AWRC Twitter account and word of mouth amongst contacts of the research team. Interested volunteers were invited to a Zoom meeting with the Principal Investigator (RY). During the meeting, suitability for the project was checked through verbal completion of an exercise readiness questionnaire and the study protocol was explained. A familiarization visit to the AWRC was scheduled to demonstrate the PAE equipment and measurement tools. During the familiarization visit, participants signed paper copies of the consent form and exercise readiness questionnaire.

Exercise protocol

Three separate sessions were scheduled with three or four machines tested during each session as detailed in Table One:

Table 1: Machines per session

Session One	Session Two	Session Three
Cross Cycle	Flys & Thighs	Side Bend Stepper
Chest and Legs	Seated Climber	Tummy Crunch
Rotary Torso	Ab Pullover	(Recumbent) Side Flexor

	Tricep Dip & Leg Curl	(Recumbent) Hipster

Participants were instructed to exercise at a rate of perceived exertion of 3/10 during the first minute on each machine. During the second minute the rate of perceived effort was increased to 4/10 and then to 6/10 during the third and fourth minutes. The final fifth minute was instructed as a cool down at a rate of perceived exertion of 3/10.

Data collection

Muscular activity was detected through surface electromyography (EMG). Electrodes were placed on the biceps brachii, triceps (lateral head), biceps femoris and rectus femoris of the right and left limbs. During session one, maximal voluntary contraction (MVC) tests were performed on each muscle to establish the 100% effort. Each muscle was tested in mid-range with the instruction to push as hard as possible against an unmovable object. Figure One is an image of the biceps brachii test using a 35KG dumbbell which was unliftable for all participants. Three tests were recorded for each muscle with a one-minute rest between each effort.

Figure 1: Maximum Voluntary Contraction Testing

During each exercise session, the surface EMG electrodes were placed over the target muscle fibres and ten seconds of performance was recorded at the start of minute three on each machine.

Cardiopulmonary exercise testing (CPET) to record oxygen uptake and heart rate was conducted using a face mask. Participants wore a sealed mask over the face and nose throughout each exercise test and a heart rate monitor around the proximal upper limb.

Balance testing was conducted at the start and end of each session. Participants were instructed to sustain progressive stance conditions ranging from feet hip width apart to tandem stance with eyes open and eyes closed. The motion analysis sensors detected stability and

movement of centre of gravity relative to base of support to ascertain changes in stance before and after a session of PAE.

Data analysis

The motion analysis data from P4 and P8 underwent in-depth analysis. P4 was a female of 163 cm height and 55 KG in weight. P8 was male with height of 180 cm and weight of 80.5KG. These physically diverse participants were selected to ensure detection of the different ranges of movement performed within the recruited sample. The motion detected at the trunk, hips, knees, shoulders and elbows was analysed. Table three is a summary of the movements detected, normal available range and functional importance.

Table 3: Range of motion normal values

Joint	Movement	Normal Range (degrees)	Functional importance
Trunk	Flexion	0-75	Bending forwards Sit to stand Prevents back pain
	Extension	0-35	Looking upwards Posture Prevents back pain
	Lateral flexion	0-65	Bending sideways Carrying items Prevents pain
	Rotation	0-48	Turning Balance Prevents pain
Hip	Flexion	0-120	Climbing steps Walking Stand to sit
	Extension	0-20	Walking Balance Climbing steps
	Hip abduction	0-45	Walking Uneven terrain Balance
	Rotation	-45 to +45	Balance Agility
Knee	Extension to Flexion	-5 to 140	Walking Standing Sit to stand
Shoulder	Extension to flexion	-50 to 180	Reaching Carrying
	Adduction to abduction	-50 to 180	Reaching Balance Carrying
	Internal to external rotation	-90 to 90	Mobility Prevent pain

Elbow	Extension to flexion	0 to 150	Carrying Lifting

The CPET data was used to determine the metabolic equivalents (METS) of each exercise test. The analysis of oxygen uptake, carbon dioxide exhaled and heart rate is required for accurate calculation of METS data and enabled comparison of PAE with other forms of exercise or activity. METS values are displayed in Table Four.

Table 4: METS values

METS Value	Equivalent activity
1.0	Desk work
2.0	Walking slowly
3.0	Walking at 3mph Sweeping floors
4.0	Brisk walking Yoga
5.0	Tennis doubles
6.0	Dancing (medium effort)
7.0	Jumping jacks
8.0	Basketball
9.0	Jogging at 6mph
10.0-14.0	High intensity activities: running, hard effort swimming, squash

The peak, mean and range of heart rate and METS values were averaged across the group of participants to determine the aerobic and metabolic demand of each machine.

The EMG data was examined for patterns of muscular contraction. The peak electrical activity was selected for each data set containing patterns of muscular contraction and the % of maximal contraction was calculated. The mean of the % values were calculated across the group of participants.

3. Results

Nine adults volunteered to participate in the project. On screening, all participants consented and signed an exercise readiness declaration.
The details of the participants are displayed in Table 5:

Table 5: Participants

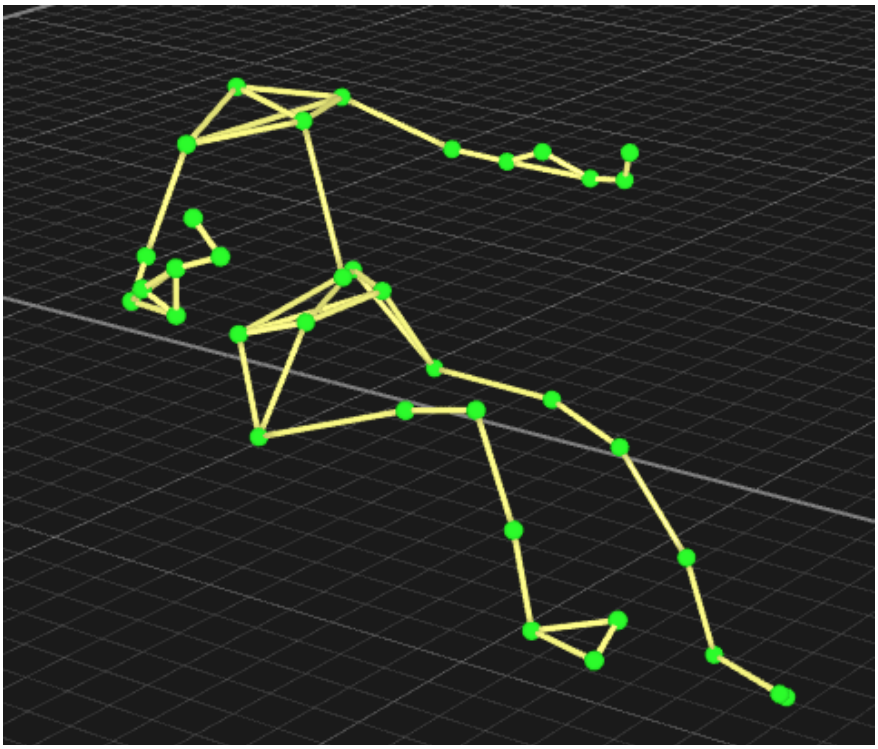
Participant code	Age	Sex	Self-reported activity levels
P1	58	F	Hill walking and canoeing
P2	67	M	Walking and woodland volunteer
P3	68	M	Frequent cyclist up to 100 miles per day
P4	75	F	Walking and active family/social life
P5	63	M	Active lifestyle including cycling
P6	56	F	Walking and attends gym 2-3 times per week
P7	57	M	Walking and strength training
P8	78	M	Walking and active social/family life
P9	65	M	Long distance and frequent walker

P7 discontinued participation due to work commitments. The remaining eight participants attended all three sessions.

CROSS CYCLE

The Cross Cycle is a seated machine which assists a cycling action of the lower limbs and reciprocal flexion and extension of the upper limbs. The markers detected on the Cross Cycle are displayed in Figure 2.

Figure 2: Cross Cycle



Cross Cycle: Motion Analysis Data

The upper and lower limbs were assisted through large ranges of flexion and extension at the upper and lower limbs. These movements are important for reaching, stepping and overall agility. The values detected are recorded in Table 6. Extension of the shoulder was detected which will stretch the soft tissues in the pectoral region. Trunk rotation was also detected, with a mean range of 30.9 degrees recorded in sync with the side of lower limb extension. Trunk rotation is needed for balance and posture.

Table 6: Cross Cycle Motion Data

Cross Cycle				
Hips	Range of flexion	Minimum flexion angle (mean)	Maximum flexion angle (mean)	Total range of hip flexion (mean)
		37.2	72.3	35
Knees	Range of flexion	Minimum flexion angle (mean)	Maximum flexion angle (mean)	Mean total range of knee flexion
		27.0	89.2	62.1
Shoulders	Range of flexion and extension	Extension angle (mean)	Flexion angle (mean)	Total range of flex/ext
		6.8	32.3	39.1
Elbows	Range of flexion	Minimum flexion angle (mean)	Maximum flexion angle (mean)	Mean total range of elbow flexion
		12.5	121.6	109.06
Trunk	Range of rotation	Mean rotation left	Mean rotation right	Mean range of rotation
		13.7	17.26	30.9

Cross Cycle: CPET Data

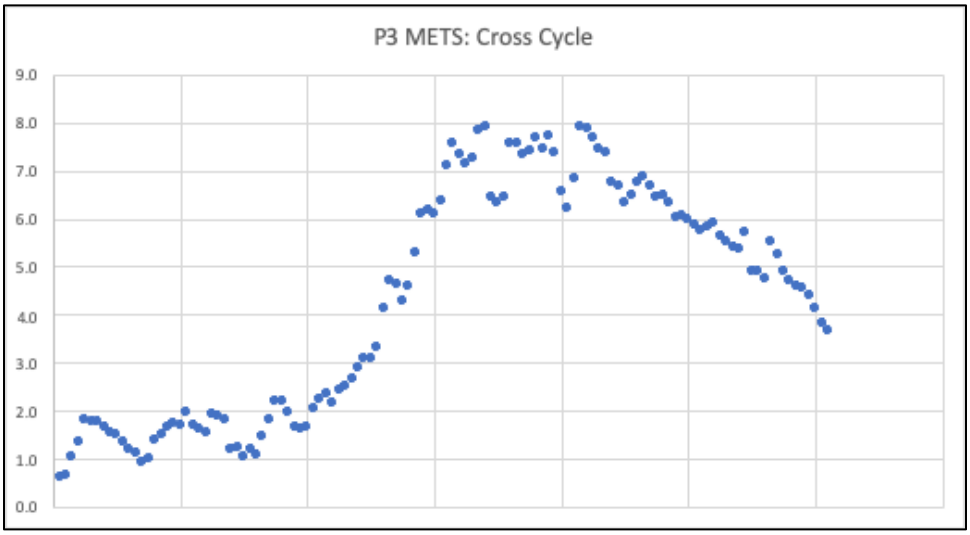
The CPET data indicated that the Cross Cycle is a moderate intensity exercise machine when user effort is applied. The peak MET value recorded was 7.9 from P3 which is equivalent to jogging or playing basketball. The changes in heart rate and calculated METS indicate that all participants increased the aerobic and metabolic demand of exercise during the five-minute test.

Table 7: Cross Cycle CPET Data

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	4.1 (2.6 - 5.03)	5.6 (4.2 - 7.9)	2.76 (1.3 - 7.3)	105 (71 – 126)	120.7 (102 – 138)	37 (14 – 60)

Figure Three displays the trajectory of METS data recorded for P3 whilst exercising on the Cross Cycle. At the start of the test the metabolic demand was minimal indicating a state of rest. The intensity of activity increased quickly and peaked at 7.9 METS during the third and fourth minutes.

Figure 3: METS Data



Cross Cycle: EMG Data

Patterns of muscle activity were detected across all recorded muscle groups. The percentage of the maximum voluntary contraction recorded is detailed in Table 8:

Table 8: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Biceps	27.3
Triceps	53.6
Rectus Femoris	54.0
Biceps Femoris	20.1

CHEST & LEGS

The Chest & Legs is an easy to access machine which assists bimanual flexion and extension of the upper and lower limbs. Figure 4 displays the start position and Figure 5 displays the markers detected at the end position.

Figure 4: Chest & Legs Start Position

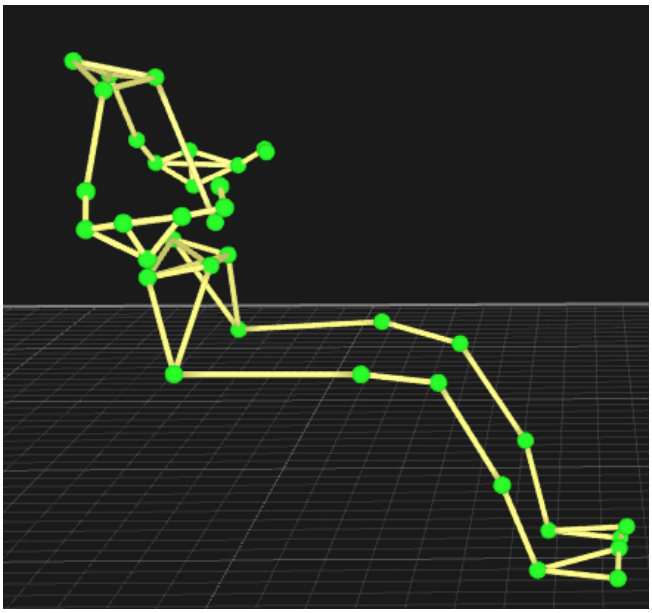
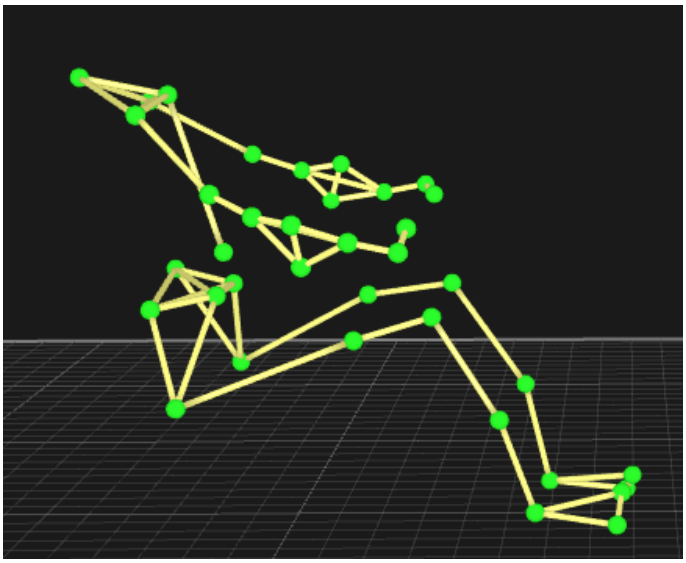


Figure 5: Chest & Legs End Position



Chest & Legs: Motion Analysis Data

The motion analysis data confirm patterns of flexion and extension assisted through the upper and lower limbs. The hips and knees move through middle and inner ranges of movement at an amplitude accessible for people with limited mobility. The shoulders are assisted into a mean of 28.06 degrees of extension which will enable a stretch of the pectoral muscles which are often tight amongst older adults.

Table 9: Chest & Legs motion data

Chest & Legs				
Hips	Range of flexion	Mean minimum flexion angle	Mean maximum flexion angle	Mean total range of hip flexion
		51.4	80.3	28.8
Knees	Range of flexion	Mean minimum flexion angle	Mean maximum flexion angle	Mean total range of knee flexion
		48.5	80.1	31.6
Shoulders	Range of flexion and extension	Mean extension angle	Mean flexion angle	Mean total range of flex/ext
		28.06	24.3	52.4
Elbows	Range of flexion	Mean minimum flexion angle	Mean maximum flexion angle	Mean total range of elbow flexion
		2.9	34.08	31.09

Chest & Legs: CPET Data

The CPET data collected during testing of the Chest & Legs machine indicates a moderate aerobic effort exerted by most participants. The mean METS across the whole five-minute test was 4.1 which is comparable with brisk walking. On average, participant heart rate increased by 30 beats per minute on the machine with P3 and P6 increasing by over 50 beats per minute.

Table 10: Chest & Legs

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean (range)	4.1 (2.6 - 5.6)	5.5 (4.3 - 7.4)	2.9 (0.8 - 6.1)	111 (83 – 151)	124 (93 – 157)	30 (9-51)

Chest & Legs: EMG Data

Patterns of activity were detected in the bicep, triceps and rectus femoris muscles during use of the Chest & Legs machine. The biceps recorded the highest bursts of contraction relative to the maximum with a mean of 66.3% calculated. The EMG data for the Chest & Legs machine are detailed in Table 11.

Table 11: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Biceps	66.3
Triceps	36
Rectus Femoris	34

ROTARY TORSO

The Rotary Torso is a seated machine which assists rotation of the spine. The shoulder and pelvic girdles are moved in opposite directions. The trajectory of movement is displayed in Figures 6 and 7.

Figure 6: Rotary Torso

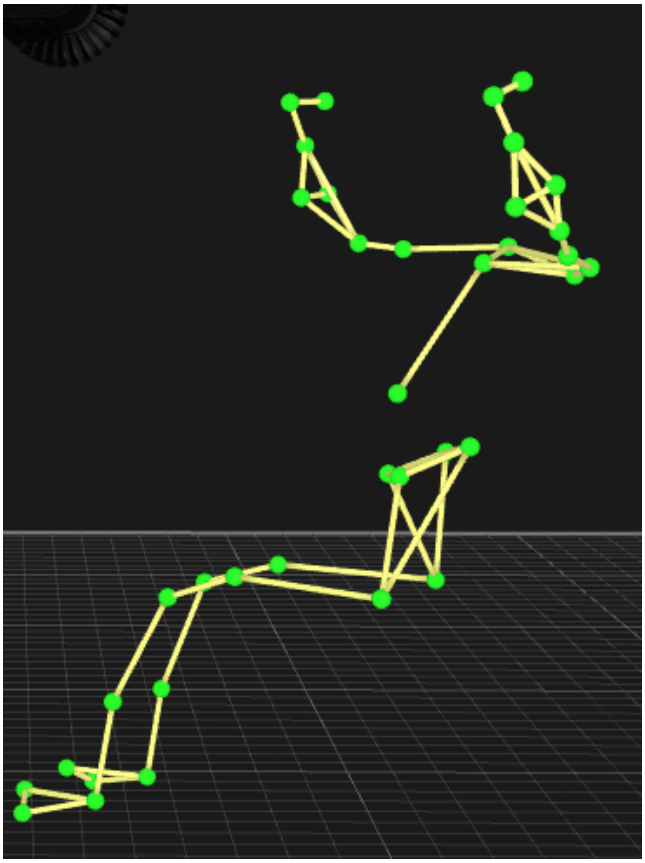
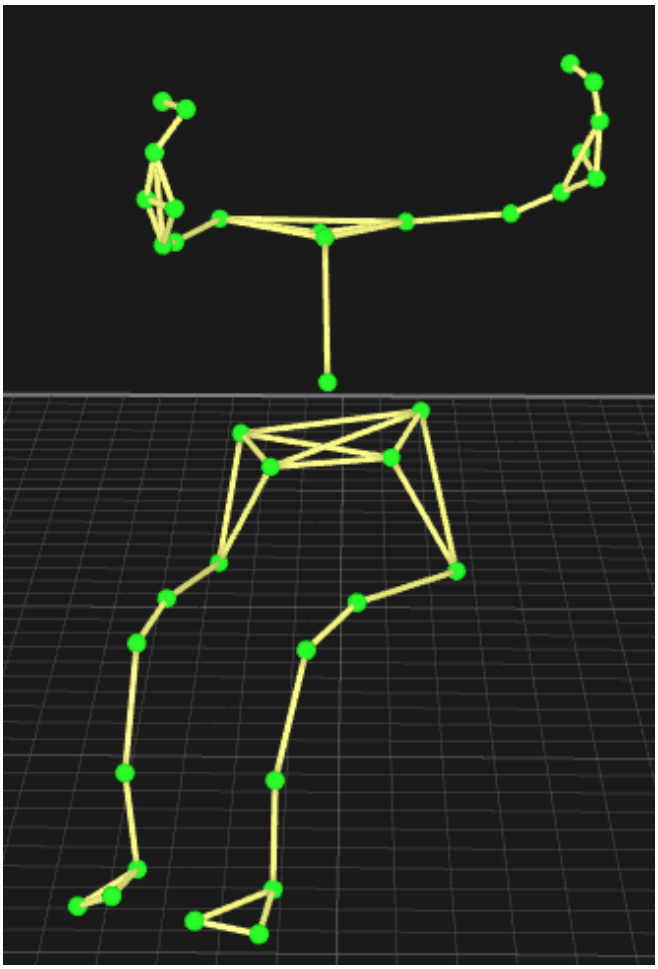


Figure 7: Rotary Torso



Rotary Torso: Motion Analysis Data

The motion analysis data detected a sustained position of trunk extension throughout the movement combined with rotation and lateral flexion. The total range of rotation was 13.2 degrees. The hips moved through a large range of adduction into abduction with a mean total range of 44.3 degrees recorded. This movement is important for balance and foot placement. Abduction and rotation were also detected at the shoulder joints.

Table 12: Rotary Torso motion analysis

Rotary Torso

Shoulders	Range of abduction into adduction	Maximum abduction (mean value)	Maximum adduction (mean value)	Mean total range of adduction into abduction
		3.96	53.28	49.7
Shoulders	Range of rotation	Maximum lateral rotation (mean value)	Minimum lateral rotation (mean value)	Mean total range of shoulder rotation
		74.1	29.5	44.5
Hips	Range of abduction into adduction	Mean maximum hip abduction	Mean maximum hip adduction	Mean total range of abduction into adduction
		20.76	-23.5	44.3
Trunk	Range of extension	Minimum extension	Maximum extension	Range of trunk extension detected
		5.15	13.01	7.86
Trunk	Range of rotation	Rotation towards left	Rotation towards right	Total range of rotation
		7.96	5.25	13.21

Rotary Torso: CPET Data

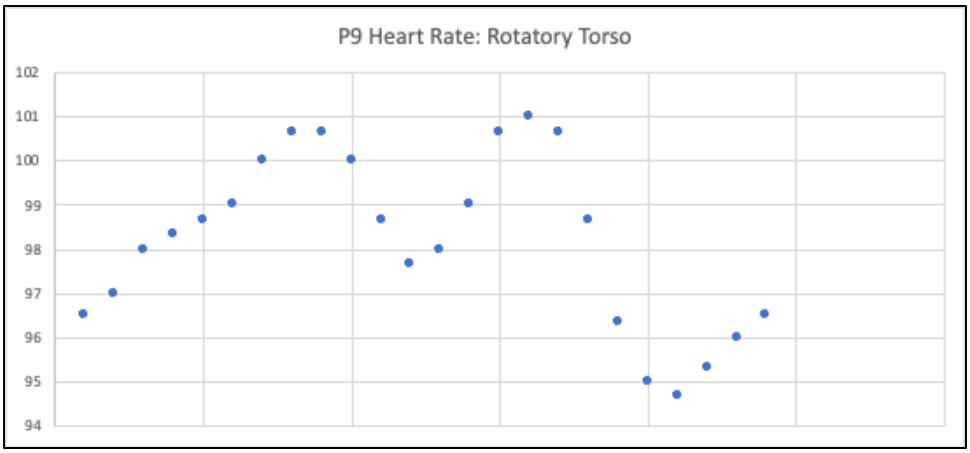
The metabolic demand of exercising on the Rotary Torso varied across participants. P2 had an elevated heart rate (134-146) throughout the exercise which may have been due to prior exercise on the Cross Cycle and Chest & Legs machines during the same data collection session. Overall, the Rotary Torso CPET data indicated a moderate intensity exercise with average METS of 3.02 which is comparable to walking and a mean heart rate of 108 across participants.

Table 13: Rotary Torso CPET Data

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	3.02 (1.7-4.4)	4.14 (3.3 - 5.3)	2.2 (1.3 - 3.4)	101 (78-138)	108 (85-146)	16.1 (4-40)

Figure 8 displays the relatively stable heart rate sustained by P9 during the Rotary Torso exercise. Heart rate ranged between 95 and 101 beats per minute with a decline following the instructed harder effort.

Figure 8: P9 Heart Rate



Rotary Torso: EMG Data

Muscle activity was detected in the triceps and biceps of the upper limb and rectus femoris and biceps femoris of the lower limb. The volume of activity in the biceps and triceps was similar indicating that the muscles work in a push-pull synergy on the Rotary Torso machine.

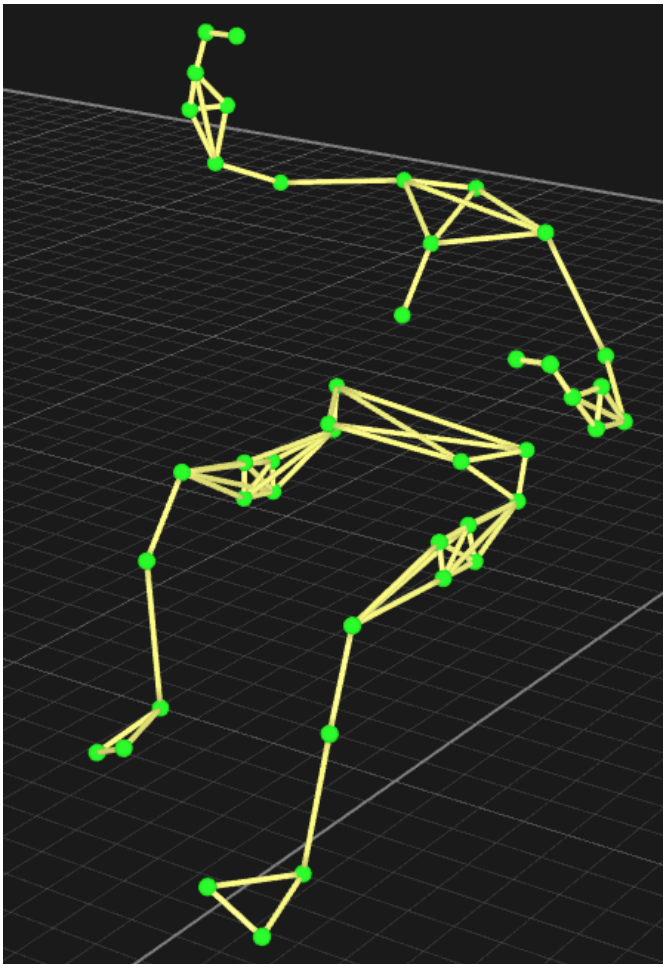
Table 14: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Biceps	26.7
Triceps	29.2
Rectus Femoris	41
Biceps Femoris	11

SEATED CLIMBER

The Seated Climber assists a reciprocal reaching action of the upper limbs and stepping actions of the lower limbs. The markers detected from the motion analysis system are displayed in Figure 9.

Figure 9: Seated Climber



Seated Climber: Motion Analysis Data

The largest amplitude movements were detected at the shoulder with an average range of 64.05 degrees of flexion recorded. This movement is important for high reaching. The elbow also moved through an average range of 16.45 degrees. Flexion and extension of the hips and knees were also recorded which are important movements for stepping.

Table 15: Seated Climber motion analysis

Seated Climber				
Hips	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Mean total range of flexion
		75.9	51.2	27.6
Knees	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Mean total range of flexion
		77.2	35.6	41.6
Shoulders	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Mean total range of flexion
		63.4	-0.5 (extension)	64.05
Elbows	Range of flexion	Maximum flexion	Minimum flexion	Range of flexion
		97.8	81.4	16.45

Seated Climber: CPET Data

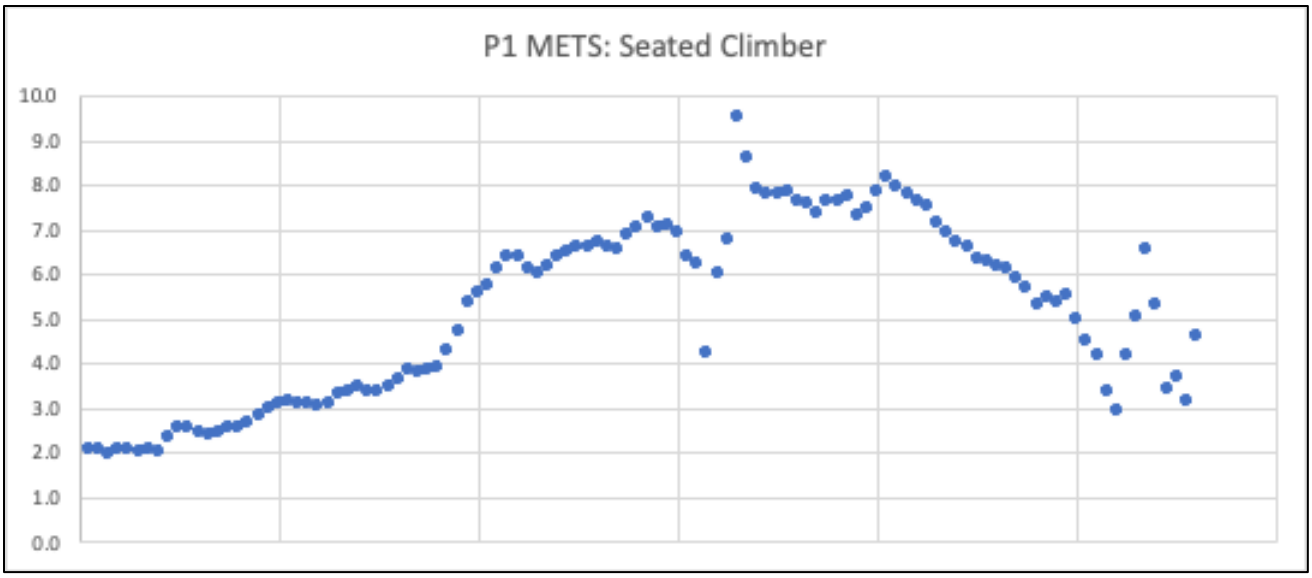
The CPET data indicated that the Seated Climber has the potential to create a high metabolic and aerobic demand as exemplified by P1 who sustained a mean MET value of 5.2 and peaked at 9.5 METS. The mean METS recorded across the group of participants was 3.14 which is equivalent to walking and represents a moderate aerobic effort.

Table 16: Seated Climber CPET Data

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	3.14 (1.7 - 5.1)	4.9 (2.2 - 9.5)	3.48 (0.8 - 7.6)	106 (80 - 151	120 (85 – 157)	39 (9-75)

The METS data calculated for P1 is displayed in Figure 10.

Figure 10: METS data



Seated Climber: EMG Data

The EMG data detected a strong effort in the triceps and rectus femoris muscles, indicating that this machine will benefit activities which require a straightening action at the knee and elbow. Activity in the biceps and biceps femoris muscles was also recorded.

Table 17: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Triceps	65.3
Biceps	17.3
Rectus Femoris	40.5
Biceps Femoris	9

TRICEP DIP & LEG CURL

The Tricep Dip & Leg Curl is a seated machine which assists the actions of a tricep dip combined with knee movement. The series of positions is displayed on Figures 11, 12 and 13.

Figure 11: Start position

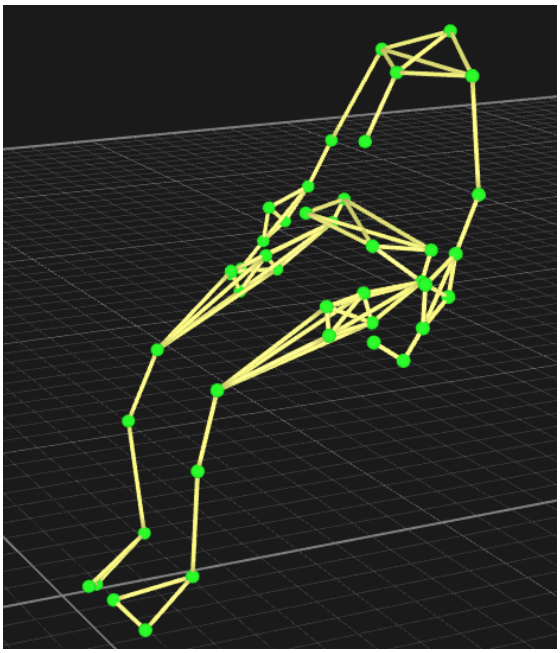


Figure 12: Mid position

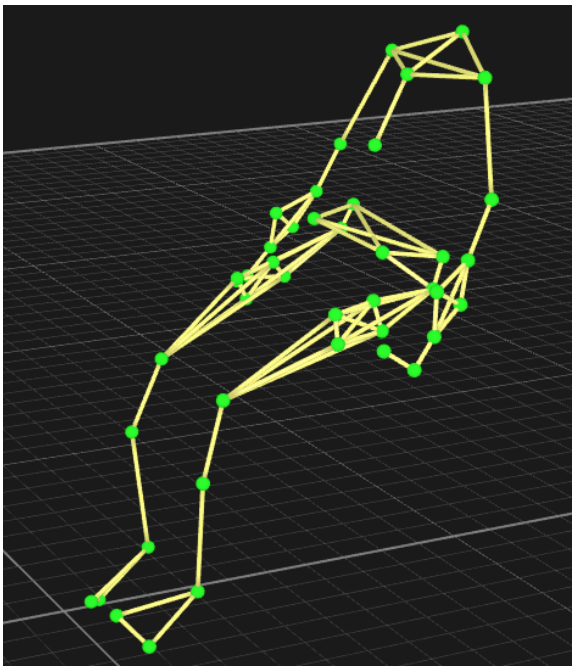
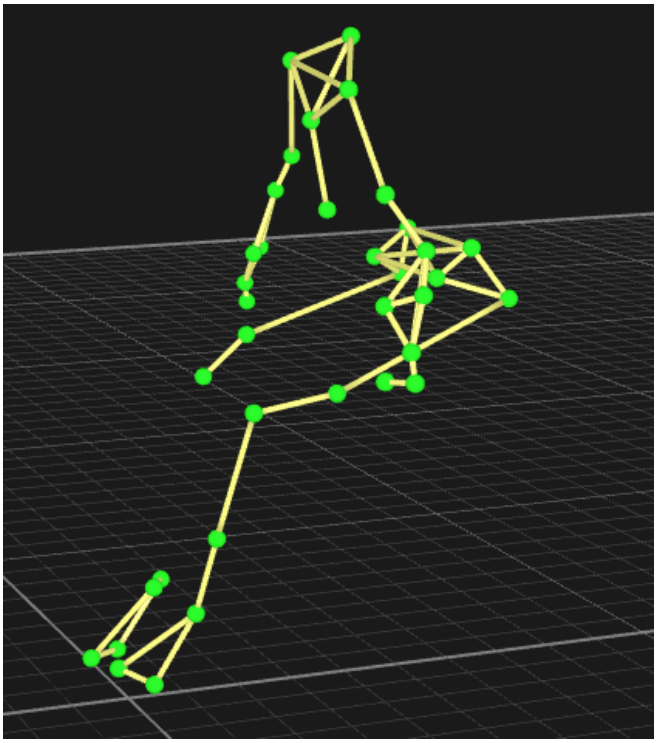


Figure 13: End position



Tricep Dip & Leg Curl: Motion Analysis Data

The motion analysis data displayed large amplitude movements at the elbows, shoulders and knees. The shoulders were predominantly active in the range of extension. The smaller participant demonstrated lateral flexion of the trunk, indicating a side-to-side movement to reach the handles. The taller participant used more trunk flexion to accompany the limb movement.

Table 18: Tricep Dip Leg Press motion analysis

Tricep Dip Leg Press				
Trunk	Range of flexion	P4 range of flexion	P8 range of flexion	Mean total range of flexion
		7.06	14.23	10.6
Trunk	Range of lateral flexion	P4 range of lateral flexion	P8 range of lateral flexion	Mean total range of lateral flexion
		34.03	2.84	18.4
Shoulders	Range of extension/ flexion	Maximum flexion (mean value)	Minimum extension (mean value)	Mean total range of extension/ flexion
		-1.82	37.07	35.2
Elbows	Range of flexion/ extension	Maximum flexion (mean value)	Minimum flexion (mean value)	Range of flexion (mean value)
		144	57.8	86.4
Knees	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Range of flexion (mean value)
		48.1	17.08	31.08

Tricep Dip & Leg Curl: CPET Data

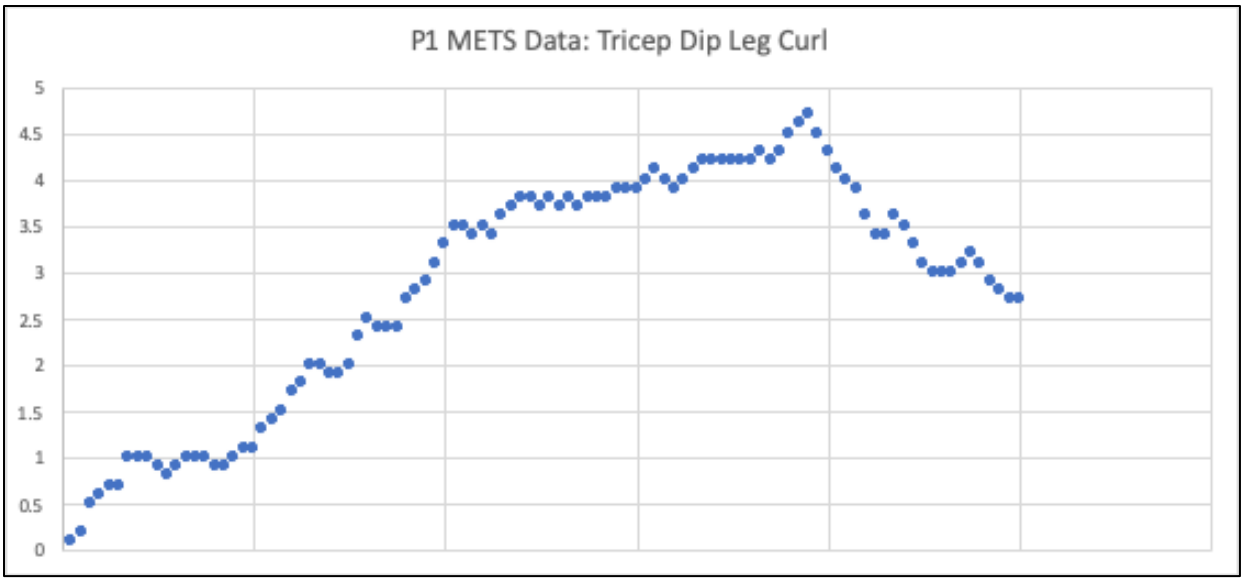
The CPET data calculated during use of the Tricep Dip & Leg Curl machine indicated a moderate aerobic and metabolic effort. The whole group mean METS was 3.43 which is comparable to walking with the mean change in METS calculated at 4.38 indicating that with harder effort the metabolic demand of using the machine can increase considerably.

Table 19: Tricep Dip & Leg Curl

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	3.43 (2.6-4.8)	5.41 (4.0-6.5)	4.38 (3.1 - 5.2)	111.4 (82 – 135)	132.8 (115 – 155)	44.3 (28 – 77)

Figure 14 displays the incline and decline of METS calculated for P1 during exercising on the Tricep Dip & Leg Curl machine.

Figure 14: P1 METS Data



Tricep Dip Leg Curl: EMG Data

Clear patterns of muscle activity were detected on the EMG whilst exercising on the Tricep Dip & Leg Curl machine. The triceps and rectus femoris muscles were active close to 50% of the voluntary maximum. The flexor muscles were active close to 25% voluntary maximum.

Table 20: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Triceps	53.7
Biceps	21.2
Rectus Femoris	47.5
Biceps Femoris	27.5

FLYS & THIGHS MACHINE

The Flys & Thighs machine is a seated machine which assists the upper and lower limbs to perform a ‘fly’ action. The start and end positions are displayed in Figures 15 and 16.

Figure 15: Start position

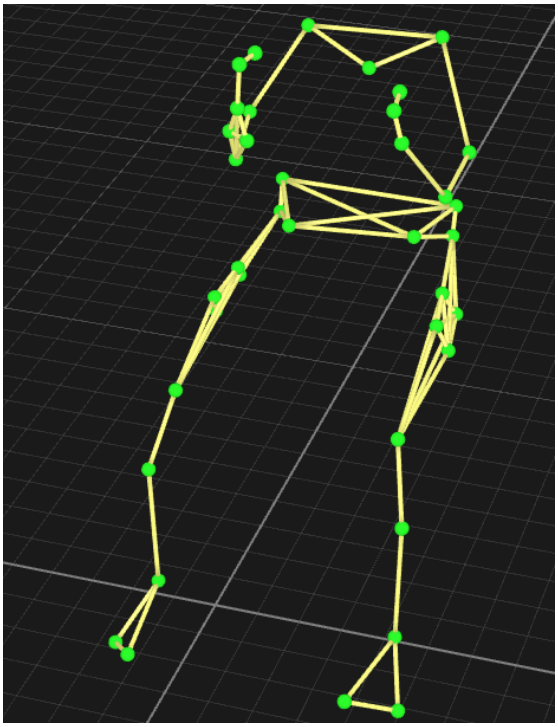
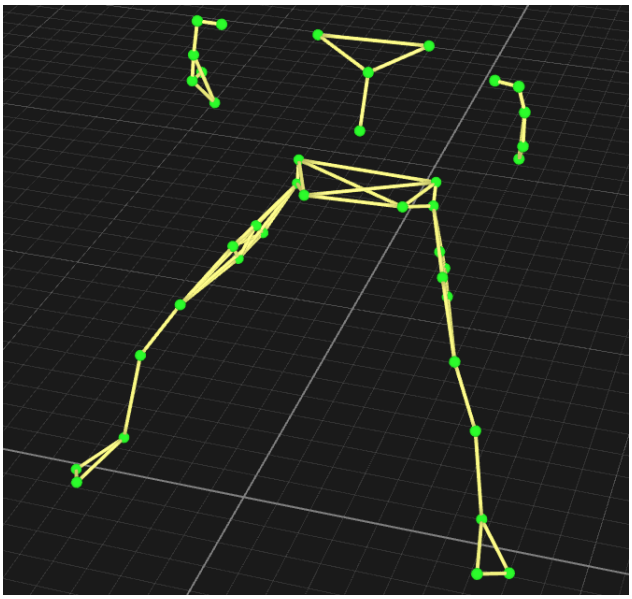


Figure 16: End position



Flys & Thighs: Motion Analysis Data

The research team encountered challenges with detection of all markers on the Flys & Thighs machine. However, patterns of abduction and adduction at the hip joints were recorded and are detailed in Table 21.

Table 21: Flys & Thighs motion analysis

Flys & Thighs Machine				
Hips	Range of abduction/ adduction	Mean minimum hip abduction	Mean maximum hip abduction	Mean total range of abduction
		6.13	25.1	18.9

Flys & Thighs Machine: CPET Data

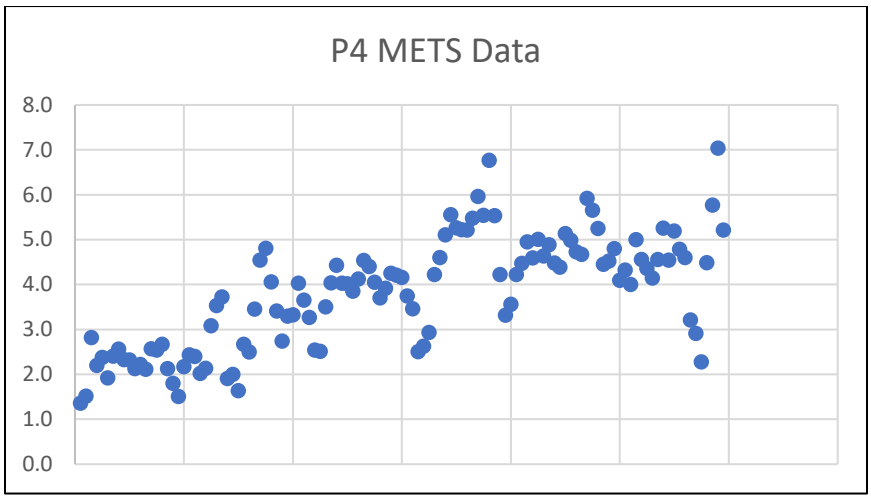
The CPET data calculated during use of the Flys & Thighs machine indicate a low intensity aerobic and metabolic demand. The mean METS calculated across the group of participants was 2.46 which is comparable with light household chores. P4 demonstrated the hardest effort on this machine with a peak METS of 7.0 indicating that moderate intensity exercise can be achieved on the Flys & Thighs machine.

Table 22: Flys & Thighs Machine

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	2.46 (1.0 – 3.0)	4.11 (1.8 – 7)	3.15 (1.5 – 5.5)	90.8 (58 – 119)	103 (71 – 136)	27.3 (13 – 40)

The overall incline in metabolic demand detected on P4 is displayed in Figure 17.

Figure 17: METS data



Flys & Thighs: EMG Data

Activity was detected in the triceps and biceps of the upper limb, and the biceps femoris of the lower limb.

Table 23: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Triceps	37.3
Biceps	16.6
Biceps Femoris	17.0

AB PULLOVER

The Ab Pullover is a machine which supports the user in a semi-recumbent start position and assists flexion of the trunk. The start and end positions are displayed in Figure X and X below:

Figure 18: Posture Pullover Start Position

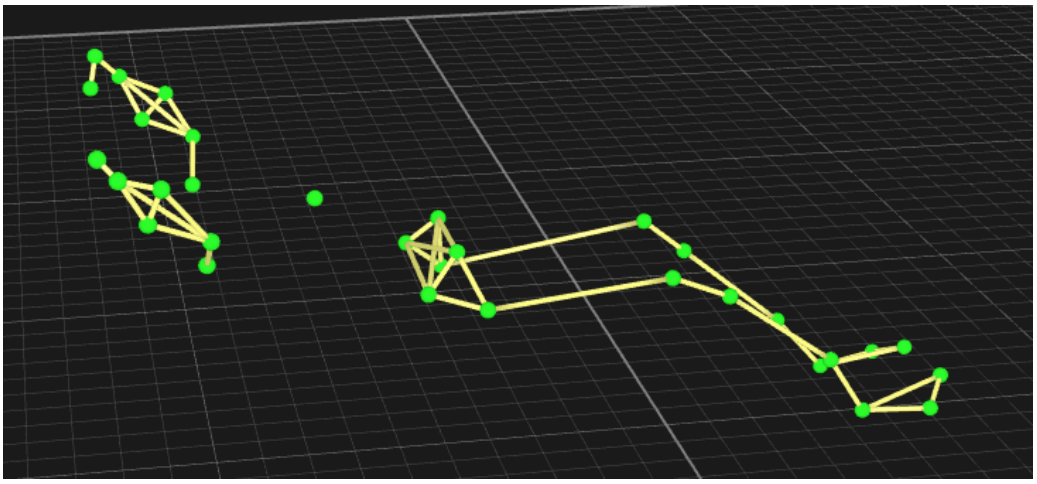
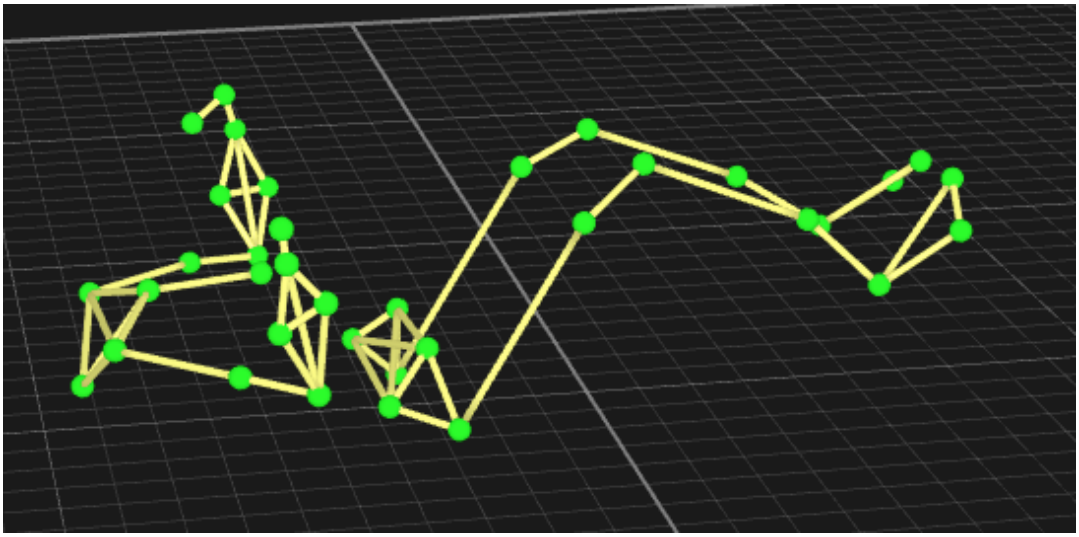


Figure 19: Posture Pullover End Position



Ab Pullover: Motion Analysis Data

Large amplitude flexion movements at the hip and knee were detected with a mean range of 59.8 degrees recorded at the hips and 35.8 at the knees.

Table 24: Ab Pullover motion analysis

Ab Pullover				
Hips	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Mean total range of flexion
		68.7	8.9	59.8
Knees	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Mean total range of knee flexion
		71.9	36.1	35.8

Ab Pullover: CPET Data

The CPET data calculated during use of the Ab Pullover indicates that this machine enables a low to moderate intensity of exercise. The mean METS calculated across the group was 2.72 which is comparable to slow walking or light household chores. The mean heart rate was 94.5 beats per minute. Harder efforts were recorded for P1, P2 and P4 who averaged 3.63 METS during the exercise test.

Table 25: Ab Pullover

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	2.72 (0.97 – 3.21)	4.45 (1.8 – 7.4)	3.46 (1.7 – 5.7)	94.5 (52 – 122)	108.6 (69 – 141)	30.6 (16 – 49)

Ab Pullover: EMG Data

Patterns of muscle activation were detected from all four muscle groups during exercise on the Ab Pullover. The rectus femoris was active at almost half the voluntary maximum and the triceps was active at a quarter of voluntary maximum.

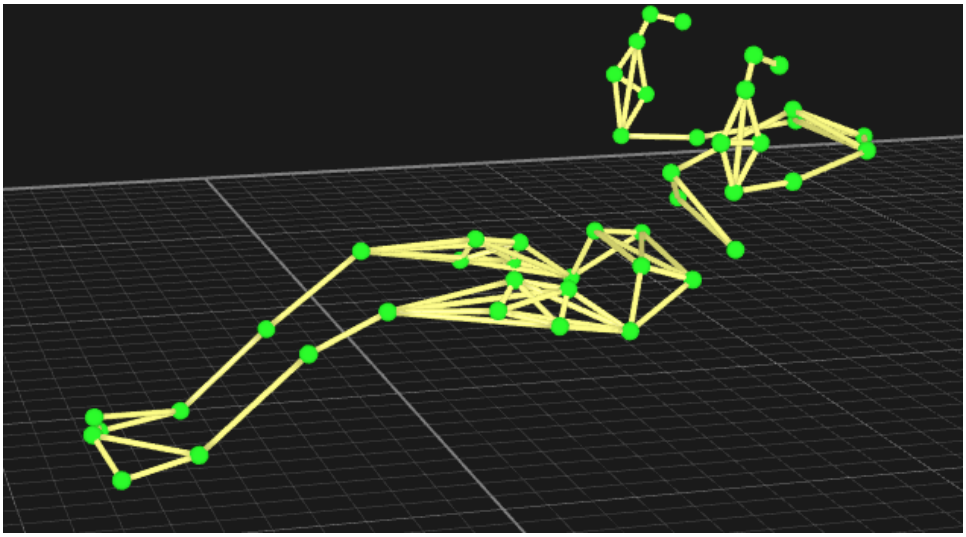
Table 26: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Triceps	24.2
Biceps	15.6
Rectus femoris	47.2
Biceps Femoris	9.0

TUMMY CRUNCH

The Tummy Crunch is part of the seated range and designed to assist repeated flexion of the trunk. Figure 20 displays the markers detected at the start position.

Figure 20: Tummy Crunch



Tummy Crunch: Motion Analysis Data

The motion analysis data confirmed the action of trunk flexion assisted by this machine. However, a difference between P4 and P8 was detected; P4 started in a position of slight trunk extension and at end of the movement was in 15.9 degrees of trunk flexion. In contrast, P8 started in 15.9 degrees of trunk flexion and finished in 41 degrees of flexion. This may be attributable to P8 being taller than P4 creating a more 'tucked in' position on the machine. The range of trunk flexion detected for both participants was similar (16.9 and 14.0). Hip flexion was detected within mid-range. Movement at the shoulders was detected with abduction occurring during the action of trunk flexion.

Table 26: Tummy Crunch motion analysis data

Tummy Crunch				
Shoulders	Range of abduction	Maximum abduction (mean value)	Minimum abduction (mean value)	Mean total range of abduction
		13.7	8.8	4.9
Knees	Range of flexion	Maximum flexion (mean value)	Minimum flexion (mean value)	Mean total range of hip rotation
		66.5	38.3	28.2
Hips	Range of flexion	Mean minimum hip flexion	Mean maximum hip flexion	Mean total range of flexion
		33.6	62.7	29.1
Trunk	Range of flexion	P4 range of flexion	P8 range of flexion	Mean range of trunk flexion detected
		-1.02 to 15.91	26.9 to 41.0	15.47

Tummy Crunch: CPET Data

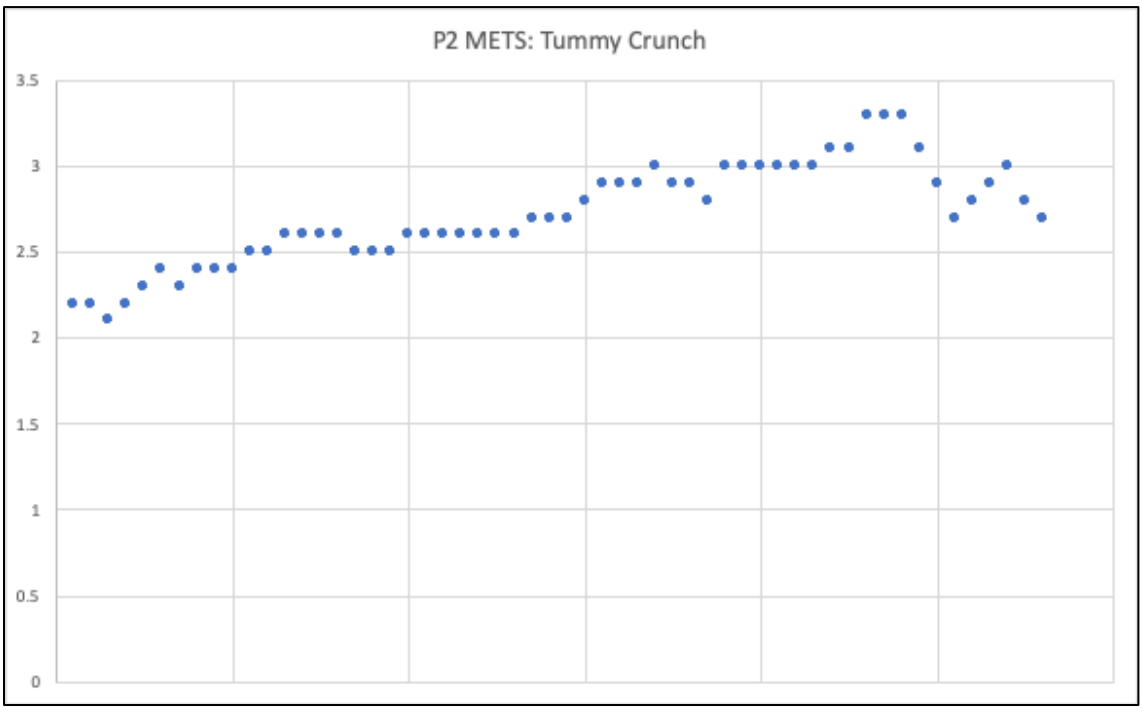
The Tummy Crunch data from the CPET indicates that this machine is a low intensity option in terms of aerobic and metabolic demand. The mean METS calculated across the group of participants was 1.87 and the peak METS averaged across the group was 2.71. These values are comparable to light housework or desk activity.

Table 27: Tummy Crunch CPET data

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	1.87 (1.55 - 2.22)	2.71 (2.5 - 3.2)	1.55 (0.4 - 2.2)	78.1 (49 – 105)	85.5 (50 – 112)	14.7 (2-38)

P2 demonstrated a greater metabolic response to the machine than the other participants. The incline and decline displayed in Figure 21 follow the instructed rate of perceived exertion effort.

Figure 21: Tummy Crunch METS Data



Tummy Crunch: EMG Data

Patterns of activity were detected in the bicep and rectus femoris muscles. The biceps were activated at 10% of the maximum voluntary contraction and synchronized with the trunk flexion action. The rectus femoris was activated during the return movement as the knees extended and the mean recorded value was 50.5% of the maximum voluntary contraction.

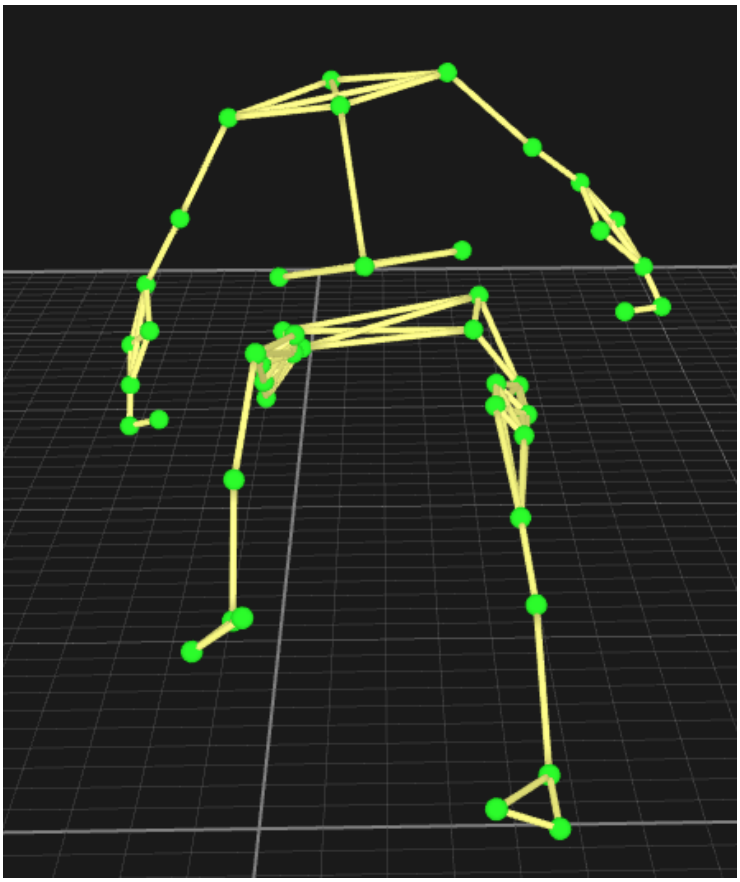
Table 26: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Biceps	10.0
Rectus femoris	50.5

SIDE BEND STEPPER

The Side Bend Stepper is a seated machine which assists lateral flexion of the trunk. The legs move upwards and downwards in a stepping action and the upper limbs can reach overhead or push down on handles at the side.

Figure 22: Markers detected on Side Bend Stepper



Side Bend Stepper: Motion Analysis Data

The motion analysis data detected flexion at the hips, knees and elbows. The hips and knees were active in the mid-range of movement, comparable to the range required to climb steps. The elbows were active in the inner range of movement which is comparable to the range used when carrying heavier items. Lateral rotation from the neutral position was detected at the shoulders, with a mean range of 14 degrees. This movement is important for reaching activities and in the prevention of shoulder pathology. The mean range of lateral flexion detected at the trunk was 15.5 degrees. This movement is important for the prevention of back pain and can improve lung capacity.

Table 28: Side Bend Stepper motion analysis

Side Bend Stepper				
Hips	Range of flexion	Mean minimum flexion angle	Mean maximum flexion angle	Mean total range of hip flexion
		50.5	88.5	28
Knees	Range of flexion	Mean minimum flexion angle	Mean maximum flexion angle	Mean total range of knee flexion
		26	109	63
Shoulders	Range of rotation	Mean minimum rotation angle	Mean maximum rotation angle	Mean total range of rotation
		28	42	14
Elbows	Range of flexion	Mean minimum flexion angle	Mean maximum flexion angle	Mean total range of elbow flexion
		3.5	38.5	35
Trunk	Range of lateral flex	Mean minimum angle	Mean maximum angle	Mean range of lateral flex
		-4.0	11.5	15.5

Side Bend Stepper: CPET Data

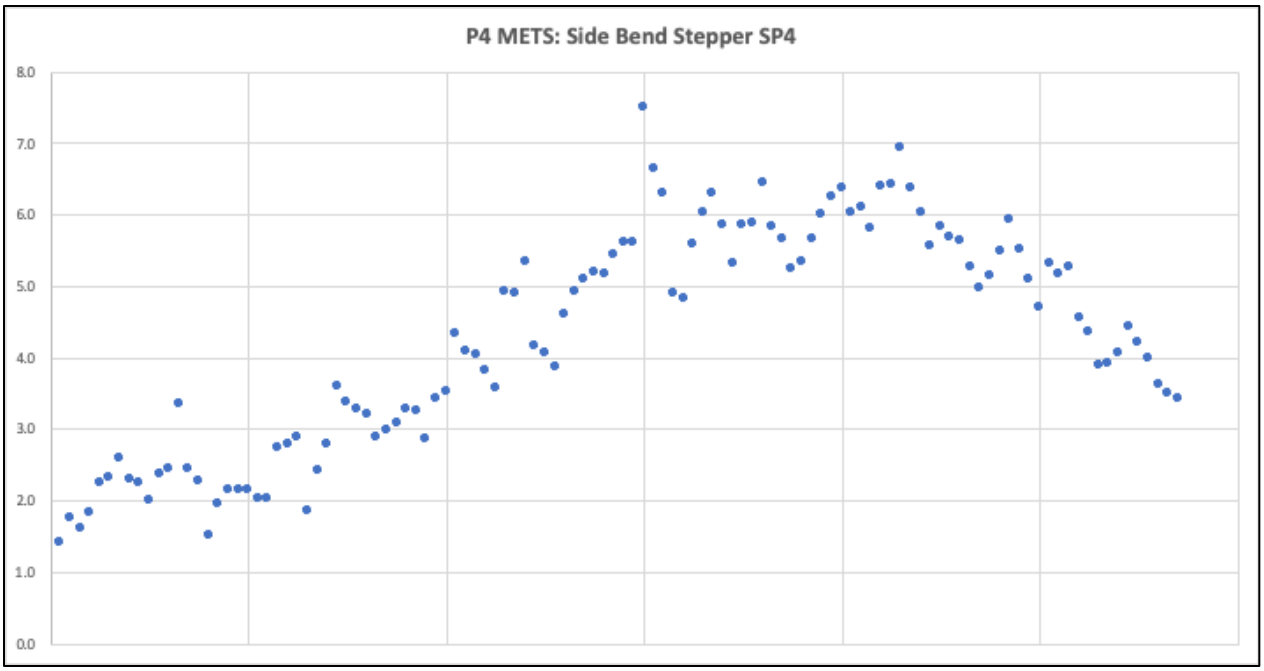
During a five-minute session on the Side Bend Stepper, the mean METS recorded at speed two was 3.65 and at speed 4 was 3.76. This is comparable to walking at steady speed or moderate/heavy household chores. The peak mean METS was 5.33 (speed two) and 5.24 (speed four). This is comparable to very brisk walking, downhill skiing or swimming at a moderate effort. On average, the heart rate increased by 46.5 beats per minute at speed four and by 30.5 beats per minute on speed two.

Table 29: Side Bend Stepper CPET

Speed Two					
Mean METS	**Mean Peak METS**	**Mean METS range**	**Mean Heart Rate**	**Mean Peak Heart Rate**	**Mean Heart Rate Range**
3.65	5.33	4.1	93.7	108.5	30.5
Speed Four					
Mean METS	**Mean Peak METS**	**Mean METS range**	**Mean Heart Rate**	**Mean Peak Heart Rate**	**Mean Heart Rate Range**
3.76	5.24	4.04	99.5	122.8	46.5

Higher readings were recorded amongst some participants, for example, P4, who peaked at 7.5 METS which is comparable to jogging or playing basketball.

Figure 23: METS recorded on Side Bend Stepper



Side Bend Stepper: EMG Data

Bursts of concentric activity were detected in the biceps, triceps and rectus femoris muscles. The average biceps activity was 10.75% of the voluntary maximum, triceps was 16% and rectus femoris was 40.5% of the voluntary maximum.

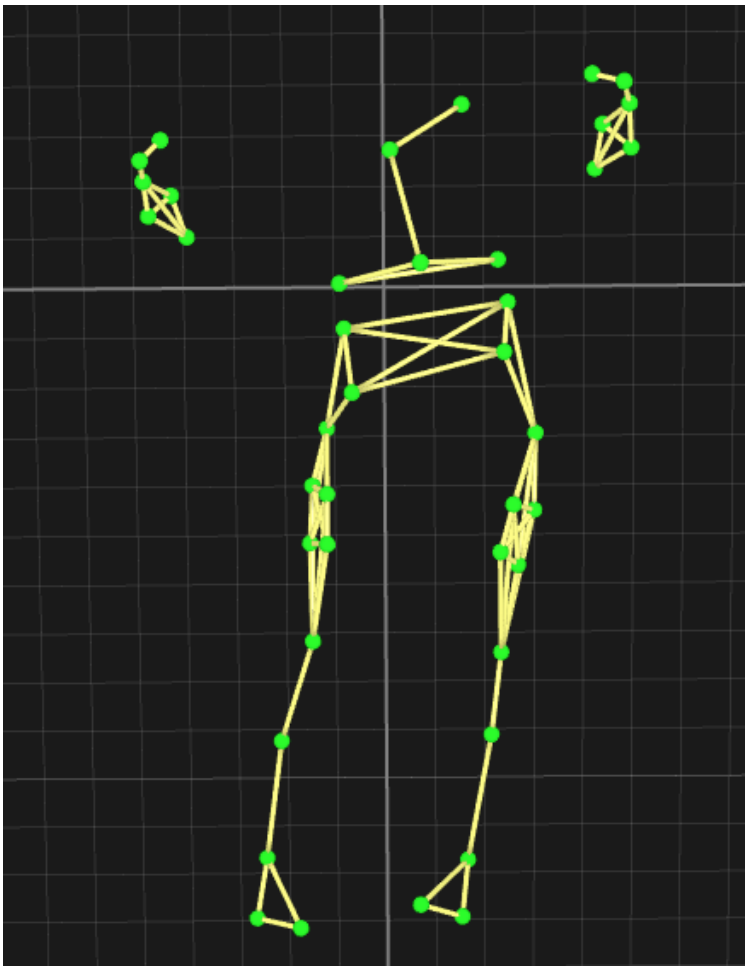
Table 26: % of Maximum Voluntary Contraction

Muscle	% Maximum Voluntary Contraction
Biceps	10.7
Triceps	16
Rectus femoris	40.5

RECUMBENT SIDE FLEXOR

The recumbent side flexor is a machine which supports the user in supine lying. The assistive mechanism enables lateral flexion of the trunk.

Figure 24: Markers detected on Recumbent Side Flexor



The mean range of lateral flexion detected was 23 degrees in each direction with a peak recording of 29.5 degrees. The mean range of trunk rotation was 16.3 degrees with a peak recording of 20.1 degrees. Lateral flexion and rotation of the trunk are important in the prevention and management of back pain. The hips were positioned in the outer range of flexion with a mean measurement of 23 degrees recorded. This will enable a stretch through the front of the hip to counteract the effects of prolonged sitting. Abduction and adduction of the hip joints were detected with a peak recording of 25 degrees of abduction. Abduction is important for balance and the ability to step sideways. The mean range of adduction recorded was 11.7 degrees which will help to stretch the soft tissues of the outer thigh. The mean range of movement between adduction and abduction at the hip joints was 23 degrees. Inward and

outward rotation of the hips was recorded with a mean value of 10.6 degrees of rotation detected from start to end points. Hip rotation is important for balance and foot placement.

Table 30: Recumbent Side Flexor motion analysis

Recumbent Side Flexor				
Hips	Range of abduction/adduction	Mean range of abduction	Mean range of adduction	Mean total range of abduction/adduction
		11.5	11.7	23
Hips	Range of rotation	P4 Mean range of hip rotation	P8 Mean range of hip rotation	Mean total range of hip rotation
		11.62	9.7	10.6
Hips	Range of flexion	Minimum mean hip flexion	Maximum mean hip flexion	Mean total range of flexion
		20.7	26.5	5.8
Trunk	Range of rotation	P4 range of rotation	P8 range of rotation	Mean range of rotation
		12.5	20.1	16.3
Trunk	Range of lateral flex	P4 range of lateral flexion	P8 range of lateral flexion	Mean range of lateral flex
		16.3	29.5	23

Recumbent Side Flexor: CPET Data

The mean recorded increase in heart rate across the participants whilst exercising on the Recumbent Side Flexor was 19 beats per minute. The variability across the group ranged from a change of 4 to 48 beats per minute indicating different levels of effort and cardiovascular response. Heart rate dropped amongst some participants whilst exercising on the Recumbent Side Flexor. The METS data indicate a low but detectable metabolic response to the machine with a mean increase of 1.32 METS across the group. The mean number of METS calculated across the whole group for the duration of exercise on the Recumbent Side Flexor was 1.43 which is comparable to seated activities. The mean peak METS calculated across the whole group was 2.8 which is comparable to walking slowly.

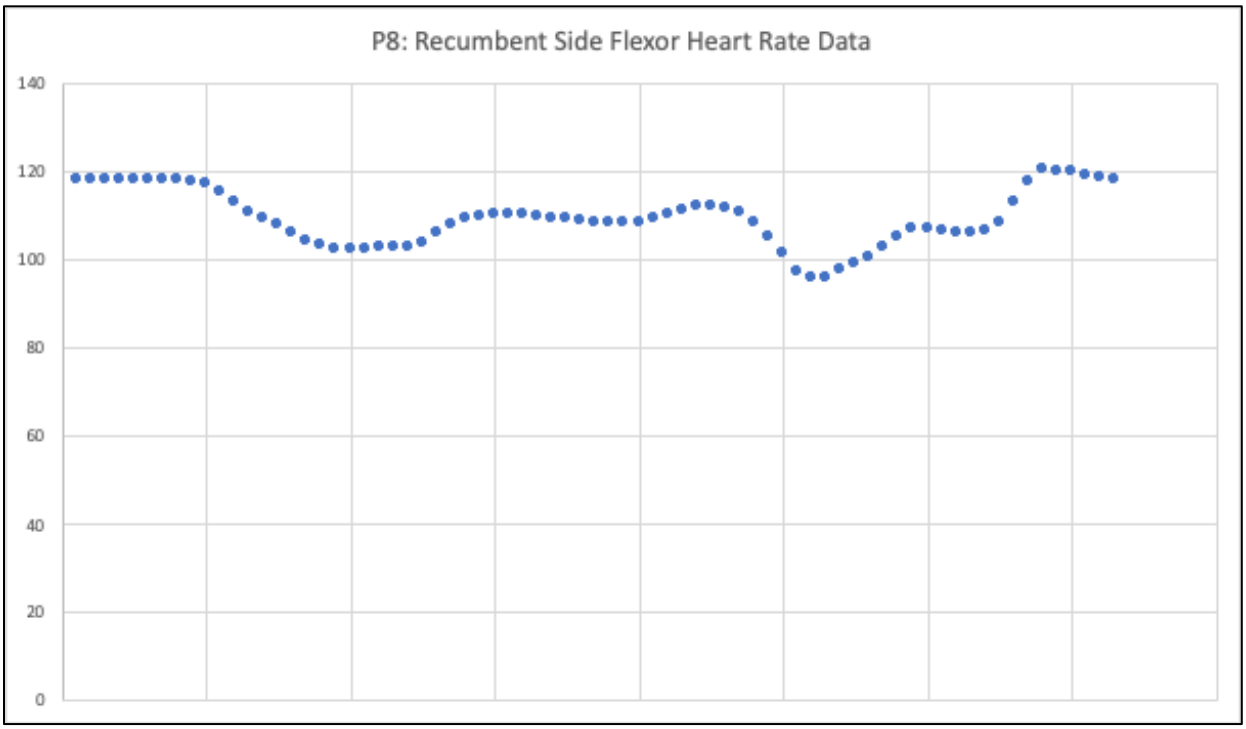
Table 31: Recumbent Side Flexor CPET

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	1.43 (1.09-3.3)	2.8 (2.3-3.3)	1.32 (1.3-2.3)	82.7 (72.8-109)	91.4 (76-120)	19 (4-48)

Figure 25 displays how heart rate was initially elevated as P8 commenced exercise on the Recumbent Lateral Flexor. This may have been due to activity associated with getting on the machine and discomfort associated with the CPET mask and sensor set up. Heart rate dropped as exercise commenced. The incline towards the end may reflect the effort associated with the

instruction to increase rate of perceived exertion, although a reduction in the final minute would have been anticipated.

Figure 25: Recumbent Side Flexor heart rate



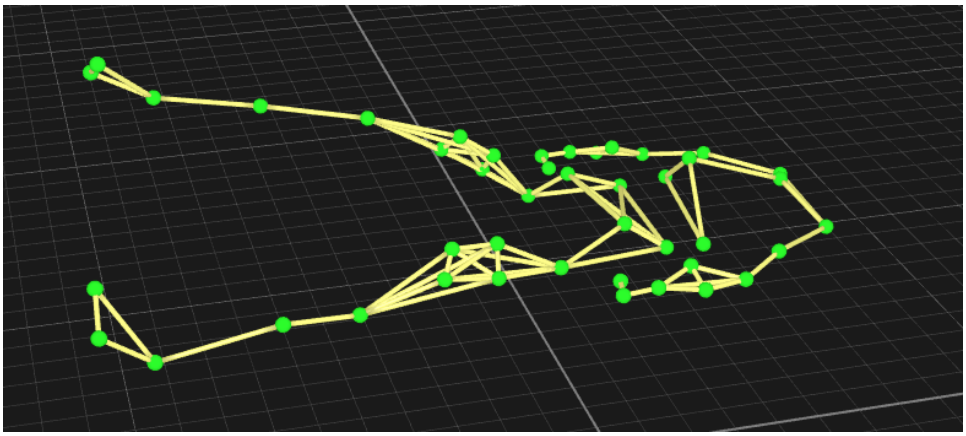
Recumbent Side Flexor: EMG Data

The upper limbs remain static on the Recumbent Lateral Flexor and therefore EMG traces were not discernable. However, some participants generated muscular activity through the Rectus Femoris with a mean value of 18.5% of the maximal voluntary contraction detected. This suggests that the quadriceps are activated in rhythm with the pelvic movement.

HIPSTER MACHINE

The Hipster machine is part of the recumbent range and assists reciprocal flexion and extension at the hips. The Hipster can be used from a supine or seated posture and data from both positions was recorded for those participants who were able to tolerate the seated position. The supine data will be reported, followed by the seated data.

Figure 26: Markers detected on the Hipster (supine)



The motion analysis data indicated that the trunk maintains a position of extension during supine use of the Hipster machine, with limited movement within this range during exercise. Maintenance of trunk extension and the ability to move the legs whilst the trunk remains relatively static are components of good posture and balance. The hips are assisted to move through the outer to middle range of flexion ranging through an average of 40.3 degrees of movement. Hip flexion is important for walking and stepping. Hip rotation was also detected, with a mean range of 17.25 degrees per full cycle of movement. Whilst exercising on the Hipster, users may aim to keep their knees extended to stretch the hamstrings or flex the knees if required. P4 aimed to maintain knee extension and a small degree of hyperextension was detected at end of range. P8 moved the knees within the inner ranges of flexion.

Table 32: Hipster Supine Motion Data

Hipster Supine				
Knees	Range of flexion/ extension	P4 Range of knee flexion (mean of right/left)	P8 Range of knee flexion (mean of right/left)	Mean total range of flexion
		12.68 to –4.12 (extension)	43.6 to 8.32	26.0
Hips	Range of rotation	P4 Mean range of hip rotation	P8 Mean range of hip rotation	Mean total range of hip rotation
		19.68	14.9	17.25
Hips	Range of flexion	Mean minimum hip flexion	Mean maximum hip flexion	Mean total range of flexion
		24.5	64.8	40.3
Trunk	Range of extension	P4 Maximum extension	P8 Maximum extension	Mean range of trunk movement detected
		13.0	19.0	2.7

Supine Hipster: CPET Data

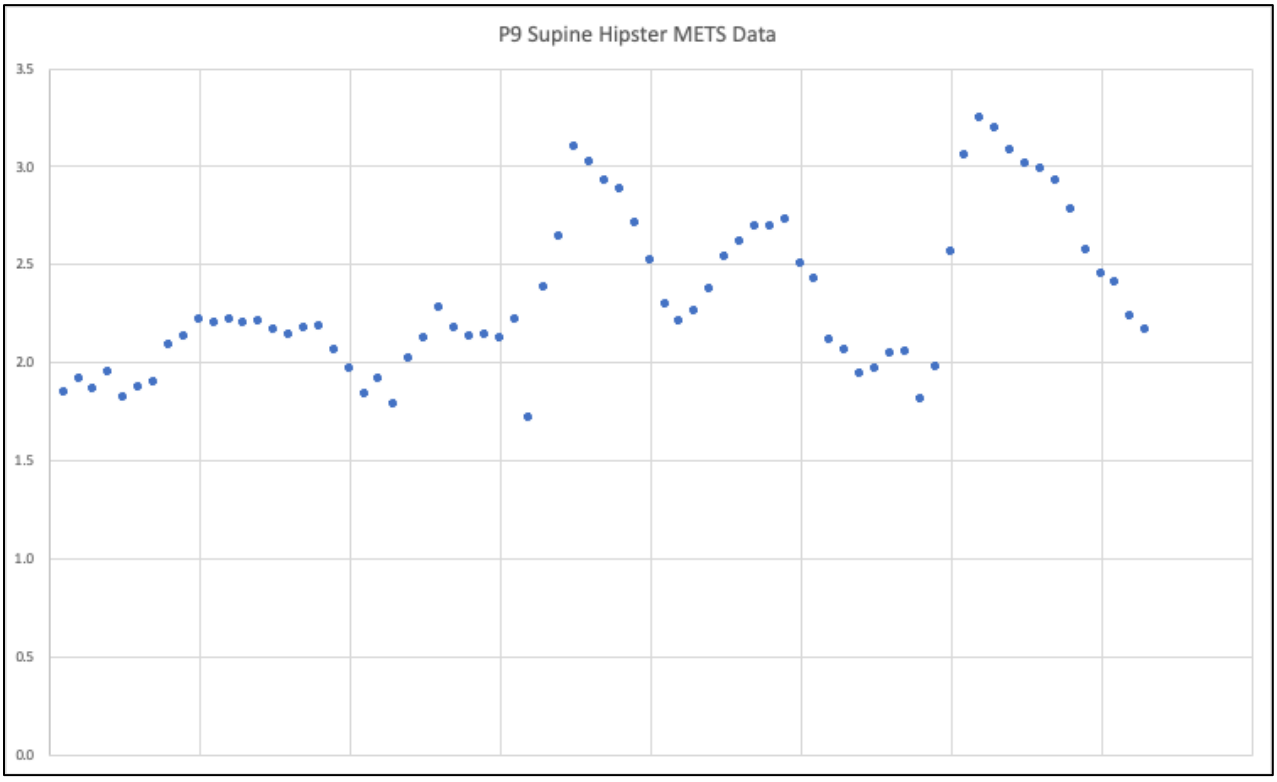
The CPET data indicated that the Supine Hipster is a low intensity exercise option. The mean variability in heart rate was 11.7 beats per minute and the mean change in METS was 1.35. The mean METS recorded across all participants was 1.9 which is comparable with light household chores. The maximum METS calculated at any point during supine use of the Hipster was 3.2 (P9) which is comparable with walking at an easy pace.

Table 33: Supine Hipster CPET

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	1.92 (1.46-2.32)	2.65 (2.0-3.2)	1.35 (0.8-1.8)	85.5 (51-103)	91.7 (52-109)	11.75 (3-16)

The METS data for P9 is detailed in Figure 27. Two inclines were recorded with the final peak synchronizing with the instruction to work at 6/10 rate of perceived exertion.

Figure 27: Supine Hipster METS Data

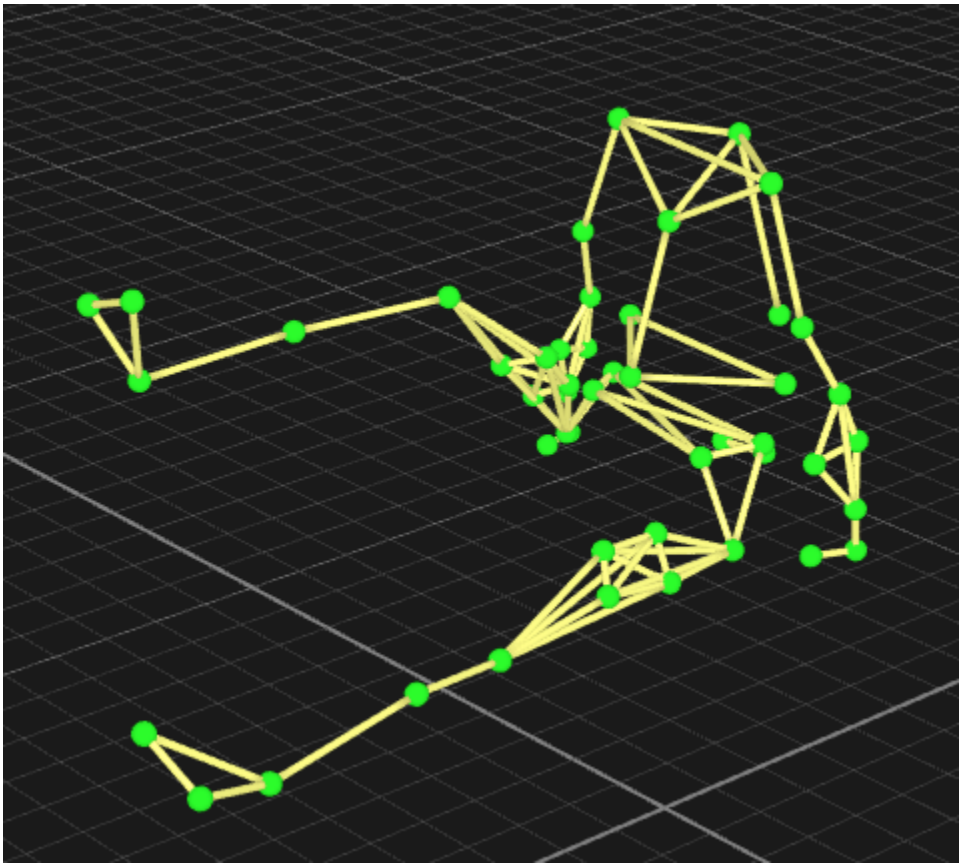


Due to the position of the Hipster relative to the EMG sensors muscular activity was not detected.

SEATED HIPSTER

Users can progress application of the Hipster machine by sitting unsupported and gaining a deeper stretch through the posterior hip during the flexion action. Six out of eight participants were able to tolerate this position. Figure 28 displays how the upper limbs were used to maintain the trunk in an upright position.

Figure 28: Markers detected on the Hipster (seated)



In sitting, the participants gained a deeper stretch through the posterior hip according to the hip flexion data with a mean maximum hip flexion recorded at 112.8 degrees. Hip rotation was detected with a mean total range of 12.4 recorded. The knees were positioned in the inner range and a small degree of hyperextension was detected at the end of the movement. The trunk was relatively static in a position of flexion throughout the exercise.

Table 34: Seated Hipster motion analysis

Hipster Seated				
Knees	Range of flexion	P4 Range of knee flexion (mean of right/left)	P8 Range of knee flexion (mean of right/left)	Mean total range of flexion
		30.3 to 7.37	39.6 to –2.18 (extension)	34.98
Hips	Range of rotation	P4 Mean range of hip rotation	P8 Mean range of hip rotation	Mean total range of hip rotation
		10.9	13.9	12.4
Hips	Range of flexion	Mean minimum hip flexion	Mean maximum hip flexion	Mean total range of flexion
		68.4	112.8	44.4
Trunk	Range of flexion	P4 Maximum flexion	P8 Maximum flexion	Mean range of trunk movement detected
		38.6	27.7	4.7

Hipster Seated: CPET Data

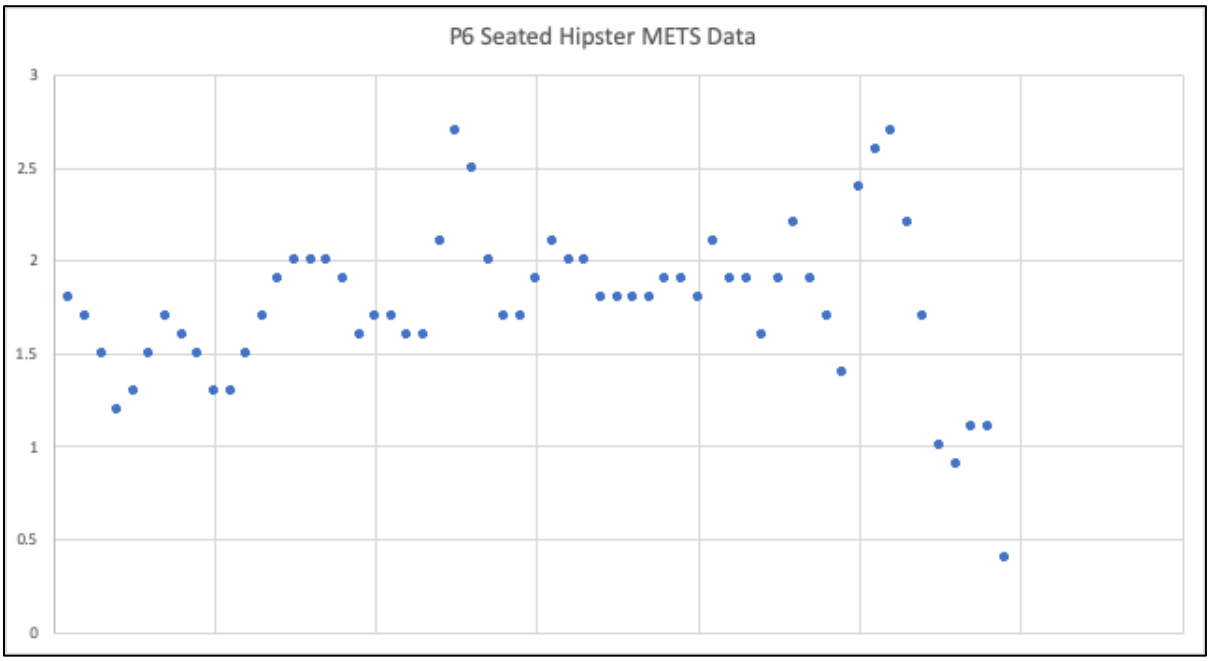
The metabolic demand of exercising on the Hipster was slightly higher than the supine position. The mean METS recorded was 2.17 compared with a mean of 1.92 in supine. The difference in peak METS was greater with 2.65 recorded in supine and 3.4 recorded in sitting. 3.4 METS is equivalent to walking or gardening indicating that exercising on the Hipster from a seated position can achieve a moderate aerobic effort.

Table 35: Seated Hipster CPET data

	Mean METS	**Peak METS**	**Mean change in METS**	**Mean Heart Rate**	**Peak Heart Rate**	**Mean change in heart rate**
Mean	2.17 (1.4 - 2.45)	3.4 (2.7-5.0)	1.83 (0.7 - 3.3)	88.9 (57.1-117))	96 (64 - 124)	13 (8-17)

Figure 29 display the METS calculated for P6 whilst exercising on the Hipster from a seated position. The trace indicates a fluctuating level of metabolic effort with a rapid decline when instructed into the final cool down minute.

Figure 29: Seated Hipster METS Data



Summary

The data across the data sets for each machine was collated to generate overall ratings of low, medium and high for the aerobic, strength, flexibility and balance benefits. These are summarised in Table 36.

Table 36: Five Elements of Healthy Ageing Summary

Machine	Aerobic/ metabolic	Strength	Flexibility	Balance
Cross Cycle	High	Legs = High Arms = High	Trunk = High Legs = High Arms = High	Moderate
Chest & Legs	High	Legs = Medium Arms = High	Trunk = Low Legs = Low Arms = Medium	Moderate
Rotary Torso	Medium	Legs = Medium Arms = Medium	Trunk = Medium Legs = High Arms = Medium	High
Tricep Dip Leg Curl	Medium	Legs = Medium Arms = High	Trunk = Medium Legs = Medium Arms = High	Medium
Seated Climber	Medium	Legs = Medium Arms = High	Trunk = Low Legs = Medium Arms = High	Medium
Flys & Thighs	Medium	Legs = Low Arms = Medium	Requires further analysis	High
Ab Pullover	Medium	Legs = Low Arms = Medium	Legs = High Trunk/arms require further analysis	High
Tummy Crunch	Low	Legs = High Arms = Low	Trunk = Medium Legs = Medium Arms = Low	High
Side Bend Stepper	High	Legs = High Arms = Low	Trunk = Medium Legs = High Arms = Medium	Medium
Recumbent Side Flexor	Low	Legs = Low Arms = Low	Trunk = Medium Legs = Low Arms = Low	Low
Supine Hipster	Low	Requires further analysis	Trunk = Low Legs = Medium Arms = Low	Low
Seated Hipster	Low	Requires further analysis	Trunk = Low Legs = Medium Arms = Low	Medium

Across the 11 machines examined, an average METS of 2.9 was recorded, indicating that the metabolic and aerobic demand of a complete circuit of PAE is comparable with walking. Bursts of higher intensity exercise were recorded indicating the potential of PAE as an interval training programme. The average muscular effort was 30% with peaks of over 50% maximal effort recorded. This is comparable with the level of effort required to improve muscular endurance and is comparable to walking or carrying moderately heavy items. Multi-directional movements of the trunk and limbs were detected on all machines including large and smaller amplitude movement.

The Cross Cycle and Side Bend Stepper are multi-purpose machines which enable a high intensity level of aerobic exercise, muscular activation and range of motion. The Chest & Legs assists a high intensity aerobic workout with activation of muscular activity. However, the range of motion is limited. The Tricep Dip & Leg Curl machine enables a moderate intensity workout with high levels of muscular activation and motion detected in the arms. The Rotary Torso and Ab Pullover machines assist large amplitude movements of the hips and are moderate aerobic intensity options. The Flys & Thighs machine is a moderate intensity option, further analysis of this machine is recommended to determine the optimal biomechanical and muscular responses. The Tummy Crunch and recumbent machines offer a lower intensity option suitable for cool down or users with fatigue symptoms.

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