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The effect of the gravity loading countermeasure skinsuit upon movement and strength

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1 ABSTRACT

2 **Introduction.** Effective countermeasures against musculoskeletal de-conditioning induced by
3 microgravity and disuse are required. A simple alternative to provision of artificial gravity by
4 centrifugation, is compressive axial loading, the Russian “Pingvin” suit was the first
5 wearable suit to apply this concept, using bungee cords, tethered, around the shoulders and
6 feet. However, poor loading characteristics, severe thermal and movement discomfort were
7 reported. The gravity loading countermeasure skinsuit (GLCS) uses a bidirectional weave to
8 generate staged axial loading from shoulders to feet, better mimicking how Earth’s gravity
9 induces progressive loading head to foot. The Mk III GLCS’s loading was evaluated and
10 tolerability assessed during maximal joint motion, ambulation and selected strength exercises.

11 **Method.** Eight subjects (5 male and 3 female; 28 ± 3 yrs; 179 ± 0.1 cm; and 74.8 ± 2.9 kg) having
12 given written informed consent, had a Mk III GLCS individually tailored. Axial loading
13 imparted, body height, joint range of motion (ROM), ambulation and strength tests (12-rep
14 max) were performed in the GLCS and gym attire (GYM), with subjective (RPE, thermal
15 comfort, movement discomfort and body control) ratings recorded throughout. **Results.**
16 GLCS provided significant axial loading when standing but significantly reduced knee (-13°),
17 spinal (-28°) and shoulder flexion/extension ROM ($-34^\circ/-13^\circ$), in addition to sit and reach ($-$
18 12.8 cm). No thermal issues were reported but there was an increase in subjective discomfort.
19 GLCS did not significantly impede strength exercise, with the exception of shoulder press
20 (15.7 ± 4.1 vs. 18.4 ± 3.4 kg). **Conclusion.** The GLCS (Mk III) demonstrates potential as a
21 countermeasure by providing tolerable, static axial loading. Furthermore, it may serve as a
22 elastic-like strength exercise adjunct, which may have utility as a rehabilitation modality after
23 further design refinement.

24 **Key words:** Gravity; resistance training; disuse; vertical compression; ambulation

1 INTRODUCTION

2 Muscle atrophy and bone demineralisation can be induced by unloading, whether through
3 disuse due to injury or illness (1) physical inactivity (2) ageing (3) or exposure to
4 microgravity (4). These, and associated cardiovascular deconditioning (5) are high priorities
5 for both space agencies and public health organisations as amelioration would improve
6 functionality, quality of life, and reduce injury and mortality risk on Earth, and in space.
7 While acute responses to microgravity (< two weeks) appear to be moderate and reversible on
8 return to Earth (5); longer term adaptations present serious risks, following prolonged space
9 missions (4,6). Bone demineralisation and loss of optimal structural architecture are
10 particularly evident in locations that are typically weight-bearing such as the lumbar spine
11 and trabecular head (2). Therefore, there is an increased fracture risk on re-exposure to
12 gravity (4,6).

13 Furthermore, microgravity-induced muscle atrophy bears some similarities to age-related
14 muscle loss or sarcopenia (3,7). Consequently, the deleterious effects of microgravity
15 exposure have led to it being termed an ‘accelerated form of ageing’ (4). Such muscle loss is
16 predominantly observed in the postural muscles, with the gastrocnemius and hamstrings
17 atrophying by approximately 20%, after more than three months in space or terrestrial bed
18 rest (9). The ability to generate power in the lower limbs (maximal explosive power; MEP)
19 has also been documented to be effected by microgravity, with one astronaut documented to
20 have reduced MEP during vertical jump testing by 67% after 21 days in space (10).

21 As a result, resistance in addition to functional (aerobic) exercises are major features of the
22 astronaut health maintenance system (4) with emphasis upon ‘anti-gravity’ muscles as little
23 muscle atrophy and bone demineralisation of the arms has been noted (11). Typically, NASA

1 and European astronauts complete four to six treadmill, two to three cycle , and six resistance
2 exercise sessions per week (12). However, this extensive countermeasure regime has to date
3 failed to completely protect against microgravity-induced physiological de-conditioning (13).
4 Furthermore, current countermeasures require significant power, volume, mass and crew
5 member time (14). Therefore, a new generation of more effective but low resource intensive
6 countermeasures are required.

7 Provision of gravity-like axial loading has obvious appeal with hyper gravity, via
8 centrifugation being proposed as a countermeasure during long term space flight (6), to
9 combat either disuse pathology or as a rehabilitation strategy on Earth (9). However,
10 significant engineering and physiological issues such as motion sickness need to be overcome
11 (14). A 'simpler' approach is to provide static axial loading to the body. The Russian TNK V-
12 1 Pingvin or "Penguin" suit which uses bungee cords around the shoulders and feet tethered
13 to a central waist belt provides significant axial loading during walking (15) and around 70%
14 body weight during treadmill running (16). Cosmonauts that adhered to treadmill exercise,
15 with the penguin suit experienced attenuated lumbar vertebrae bone mineral density loss (0-
16 3%), compared to non-adherer's (6-10%) (17). Furthermore, wearing the suit for 10 hours a
17 day with 10kg loading during bed rest preserved Soleus muscle size (18). However, anecdotal
18 reports suggest the Penguin suit imposes significant thermal and movement discomfort,
19 rendering it inappropriate to be worn for prolonged periods or during exercise. In fact, the
20 majority of cosmonauts refuse to don their suit (19) even though integration with resistance
21 training could reduce both the required workload and length of sessions (16). Such
22 discomfort may originate from the fact that the penguin suits loading regime creates pressure
23 points, as it pulls from the central waist belt, to the shoulders and feet, which is not how the

1 body is loaded on Earth, where when standing, segmental axial body weight loading occurs
2 as result of the pull of Earth's gravity (1Gz; 20).

3 The gravity loading countermeasures skin suit (GLCS) has recently been developed utilising
4 lightweight (<500g) elastic, porous, bidirectional weaves, in order to better replicate the
5 cumulative nature of axial loading as experienced on Earth (19-20). Axial loading is
6 progressively increased via material tension in the vertical axis fibres (with circumferential
7 tension sufficient to prevent suit slippage). It uses each circumferential fibre of its elastic
8 weave as a "belt" to produce numerous vertical stages; from the shoulders to the feet. Stirrups
9 wrapped around shoes (or insoles) distribute the pressure across the sole.

10 Pilot studies with the first iteration of the GLCS (mark 1) were tested using the parabolic
11 flight analogue to simulate microgravity conditions, it was determined that there was a
12 negligible impact on mobility when wearing the GLCS and skin pressure was similar to
13 wearing tight socks (4-10mmHg; 20). However, while material stretch was assessed to
14 calculate loading during the flight, actual axial loading experienced by the participant was not
15 determined and it is unknown whether the GLCS is tolerable during ambulation, daily task
16 performance or resistance exercise. Therefore the aim of this study was to assess axial
17 loading provided by a newly designed SkinSuit, the Mk III GLCS and thus determine
18 whether the additional axial loading provided by the GLCS affects tolerability and joint range
19 of motion, perceived exertion, ambulation tasks and resistance exercise performance.

20

21 **Methods**

22 **Experimental Approach to the Problem**

1 Three sessions were conducted within a seven day period with the first session comprising:
2 suit axial loading assessment, familiarisation of joint motion and ambulation tests, and the
3 determination of each subject's (safe) 12 repetition maximum (12 RM) for six selected
4 resistance exercises in loose fitting gym clothing by completing several sets of each exercise
5 with increasing weight whilst their technique was carefully monitored (experimenters were
6 qualified fitness instructors). In the subsequent two sessions, the entire test battery was
7 repeated, on one occasion when wearing the GLCS, and again at least 48 hours later when
8 wearing gym (GYM) clothing, this order was randomised and balanced.

9 **Subjects**

10 Due to the number of GLCS's available, eight young healthy participants were recruited (5
11 male; 26 ± 3 yrs; 182 ± 0.1 cm; and 76.8 ± 6.7 kg & 3 female; 32 ± 4 yrs; 170 ± 0.1 cm; and
12 71.3 ± 4.5 kg) and gave written informed consent to participate in the study which received
13 local ethics committee approval. All denied taking any medication or having a history of
14 neurological, cardiorespiratory and/or psychological disorders. None of the participants were
15 in pain, or knew/suspected that they were pregnant. Participants were instructed to abstain
16 from vigorous exercise and alcohol for at least 24 hours and from caffeine for at least two
17 hours prior to each session. Testing took place in a quiet, thermoneutral environment ($\sim 23^{\circ}\text{C}$;
18 $\sim 32\%$ humidity).

19 **Procedures**

20 All participants were provided with a custom-fabricated gravity loading countermeasure skin
21 suit (Costume Works Inc, Boston, Massachusetts, USA) which necessitated circumferential
22 measures every 2 cm vertically, from the top of the ankle to the yoke (roughly armpit level)
23 for each subject. Sizing was performed twice to ensure accuracy with a linen tape measure.

1 When participants had donned their suits they were visually checked to ensure that the
2 bottom of the suit was resting in line with the top of the ankle, as the material strain of the
3 suit had been calculated from this point to the yoke line, based on the previous GLCS
4 research (19-20)

5 Axial loading was determined via Tekscan (F-Scan, USA) pressure sensor insoles inserted
6 *underneath* the shoulder straps, and *between* the sole of the foot and the shoes (flat rigid soled
7 trainers to distribute the pressure) with GLCS foot straps fixed around the shoe. TekScan
8 sensors were calibrated with known weights prior to testing. Two measures were taken, once
9 with the subject wearing the GLCS and shoes but not strapped (i.e. not loaded), to get
10 BASELINE loading, then again when the GLCS ankle straps were looped around the foot
11 and clipped, thus stretching the material and inducing the loading. Bilateral pressure
12 measurements were obtained for 6 seconds when standing upright, with arms relaxed by the
13 sides (n=8). Total pressure (Newton/m²) when wearing the GLCS, was recorded at foot and
14 the shoulder. Loading recorded when wearing the GLCS was then expressed as an average
15 difference (Δ) from the BASELINE (without GLCS attached; 1Gz)

16 **Total Gz – BASELINE Gz = GLCS Gz.**

17 Height was measured using a standiometer (Cambridge measuring systems, UK) when
18 participants had donned the suit and at the end of the experiment, subjects were asked to
19 stand shoulder width apart during measurement and to fix their gaze forward. Joint flexibility
20 (maximal range of motion; ROM) was determined bi-laterally from three attempts (with
21 measures taken from the best stable attempt) via a bubble Inclinometer (Medical Research
22 Ltd, UK) during: knee flexion/extension, hip abduction/adduction, shoulder flexion/extension
23 and spinal flexion/extension (at both the yoke line and T12, when standing). Back flexibility
24 was assessed via Sit and Reach (22) testing where participants sat upright on a level surface,

1 with straight legs and bare feet flat against the vertical surface of a Sit and Reach Board.
2 Subjects reached forward as far as possible on three occasions with the furthest attempt
3 recorded. Participants were timed performing the Get Up and Go test (23) which required
4 rising from a seated position, walking around a stationary cone (3 metres away), and
5 returning safely to the seated position, as quickly as possible.

6 Participants performed three sets of 12 repetitions of each exercise :Dumbbell Shoulder Press
7 and Squat (Free weights, Reebok, China), Machine Chest Press and Seated Row (Multigym,
8 Bodycraft, Taiwan), Horizontal Leg Press (Laying leg press, Technogym, Italy) and Seated
9 Calf Raise (Ultimate workout, Nottingham, UK) at their pre-determined 12 RM with breaks
10 of one minute between sets and three minutes between exercises. Technique was observed
11 with improper or incomplete movement leading to exercise termination and the number of
12 completed reps, per set, recorded. Core body temperature was monitored throughout with
13 wireless pill telemetry (CorTemp sensor, HQinc, Palmetto, USA). Upon completion of each
14 set, participants rated perceived exertion (RPE; 6 = rest – 20 = maximum effort), thermal
15 comfort (ASHRAE 7-point; 0 = neutral – 3 = hot) (24) movement discomfort (1-nude
16 comfort -10 = too uncomfortable for 10 minutes) (25) and body control (1 = unrestricted -10
17 = no control) (26) on scales employed to assess space suits (27).

18

19 **Statistics**

20 Data was plotted to assess normality in SPSS (histogram, boxplots) with tests of normality
21 (Shapiro Wilk's test; SW test). Data are reported as mean \pm standard error of the mean (SEM)
22 except for changes in height (mean \pm standard deviation) and subjective ratings expressed as
23 median (interquartile range). A paired samples t-test was used to compare the average
24 difference (Δ) of loading produced at the foot and shoulder and the total height and specific

1 height difference between the Calcaneus and Illiac crest were also compared between GYM
2 and GLCS.

3
4 As no differences $>5^{\circ}$ were observed in joint ROM, the averaged best attempt for each side
5 was compared between GYM and GLCS with student paired t-tests; except for hip abduction
6 ($p=0.02$) and spinal flexion at T12 ($p=0.01$) which were non-normally distributed (SW test)
7 and thus Wilcoxon tests were employed. Student paired t-tests were also used to compare
8 GLCS vs. GYM for Sit and Reach (cm), Get up and Go (s), number of reps completed in the
9 final set (3rd), average time taken for completion of exercise sets (s). Subjective RPE,
10 discomfort, control, thermal comfort and core temperature change (SW's test $p<0.05$),
11 following exercise performance was compared with Wilcoxon non-parametric test. Statistics
12 were performed using Statistical Package for Social Sciences 19.0 (SPSS Inc., Chicago, IL,
13 USA) with statistical significance assumed when $p < 0.05$.

15 **RESULTS**

16 **GLCS Loading**

17 The Mk III GLCS provided significant axial loading (ΔGz) in all subjects imparting
18 $0.7\pm 0.3Gz$ at the feet, significantly ($p<0.005$) greater than that recorded at the shoulders
19 ($0.1\pm 0.1Gz$ - Figure 1).

20
21 ***Figure 1.***

1 The GLCS (178.7 ± 9.6) when standing induced a small non-significant reduction of height in
2 five of the eight participants vs. when wearing GYM clothing (179.7 ± 9.9 cm) garments. No
3 difference in height between the Calcaneus and Iliac crest was observed [GYM
4 (66.9 ± 5.1 cm) and GLCS (66.9 ± 3.6 cm)].

5 **Joint Motion and Ambulation**

6 GLCS significantly ($p < 0.05$) attenuated the ROM of all movements except shoulder
7 extension and hip adduction (Table 1). Sit and reach was also significantly impaired whilst
8 Get up and Go time was prolonged with the GLCS.

9

10 **Table 1.**

11

12 **Strength Exercise**

13 Participants were able to complete the 3 sets of 12 reps for nearly all the selected strength
14 exercises in both attires. The exception was shoulder press, where a mean of nine reps was
15 completed in the last set ($p < 0.05$) when wearing the GLCS (Table 2). This in turn
16 significantly reduced the average time to complete the set of shoulder exercises. Core
17 temperature remained unchanged apart from shoulder press where a greater increase was
18 reported post exercise in the GYM condition.

19

20 **Table 2.**

21

1 **Subjective Ratings**

2 Significant movement discomfort ($p < 0.01$) and body control impairment ($p < 0.01$) was
3 induced by the GLCS during all resistance exercises (Table 3).

4 5 **Table 3.**

6
7 Rating of perceived exertion was significantly ($p < 0.05$) higher during shoulder press (vs.
8 GYM) only (Table 4). No significant differences in thermal comfort were reported.

9 10 **Table 4.**

11 12 **DISCUSSION**

13 The main findings of the study were that wearing the GLCS (Mk III) provides approximately
14 ~0.7Gz axial loading at the feet, whilst there was a significant reduction in the maximal joint
15 range of motion, this only had a minor encumbrance in the ability to perform resistance
16 exercise. Core temperature and thermal comfort during strength exercise did not differ
17 between attire, though there was a significant increase in movement discomfort and control
18 required to perform the exercises. During the initial trials subjects found donning and doffing
19 the GLCS challenging, especially with getting their shoulders into the garment and tightening
20 the stirrups, however participants noted this became easier with more practice.

1 The GLCS provided an additional axial load of approximately 0.7Gz, albeit with a broad
2 range (0.53-1.12Gz). Variation in axial loading between subjects appeared not to be
3 dependent upon gender or stature but may relate to inaccuracies in fitting measurements
4 and/or wear of the suit. This range in loading may also be due to differences in stirrup
5 tightening/loosening as once the study commenced no adjustments were made. Having live
6 feedback on what axial loading is being provided might facilitate greater consistency. This is
7 especially important across multiple donnings and where microgravity/immobilisation
8 induced fluid redistribution (28), anthropometric changes (29-30) or exercise could
9 conceivably alter the loading. Furthermore, whilst not explicitly tested the axial loading
10 appears to be dependent upon posture. Thus, ability to adjust axial load with real time
11 feedback, would be advantageous for application in both user groups on Earth and space
12 where astronauts adopt a “neutral” floating (14).

13 Though significant loading was recorded, it is presently unknown as to what an appropriate
14 static axial load stimulus might be to attenuate musculoskeletal deconditioning experienced
15 in disuse and microgravity, either alone or in combination with exercise (7). Whilst no direct
16 comparison with the Pingvin suit was conducted, the Mk III GLCS appears to induce axial
17 loading not dissimilar to the 70% of the subject’s bodyweight reported during running.
18 However, unlike the Pingvin suit, no thermal tolerance issues arose when wearing the GLCS
19 during exercise, presumably due to fabrication with porous material (15, 19). The material
20 tension created by the elastic weaves in the GLCS also creates vertical tension, which is more
21 analogous to the way the body is loaded on Earth, than the bungee cords in the Pingvin suit.
22 This can be observed in the low pressure recorded at the shoulder and increased pressure at
23 the feet, which likely contributes to its improved tolerability during exercise (20).

1 When wearing the GLCS for an acute period of time (~2h), total standing height was reduced
2 by ~ 1cm, presumably due to the compression on the intra-vertebral disks, as leg length
3 measured from the Calcaneus to the Iliac crest remained unchanged. If confirmed this may be
4 advantageous in mitigating spinal elongation during immobilisation on Earth (31, 32) and
5 when in space, which has been reported to be as much as 7cm (31). Such elongation can be
6 painful and de-habilitating as well as leading to increased risk of disc herniation (31).
7 However in potential future studies focusing on elongation, standardisation of height
8 assessment to improve reliability should be implemented, as gaze stabilisation was only
9 subjectively controlled, this could be improved by placing fixed markers and pointers to
10 reduce error.

11 Whilst all maximal joint ranges of motion tested were attenuated by GLCS wear it is rare to
12 require the full range of motion during normal daily activity and as subjects reported few
13 difficulties, functional significance appears minor. Timed Get up and Go was slower but from
14 anecdotal reports may have at least in part due to a reluctance to tear the seams of the suit,
15 rather than locomotion impedance per se, this might be a potential limitation and could
16 indicate greater familiarisation with the GLCS is required prior to testing.

17 The Pingvin suit has been reported to elevate core temperature and induce thermal discomfort
18 during exercise (33). In contrast, the GLCS had no effect upon strength exercise-induced core
19 temperature or thermal comfort in normal ambient conditions (analogous to the international
20 space station (12)). Movement discomfort and body control were significantly increased
21 whilst wearing the GLCS compared to GYM clothes, suggesting the GLCS could be
22 optimised to improve comfort especially near the shoulder. However, it is important to note
23 that comparison with loose fitting clothing is potentially misleading and a limit of this study,

1 thus, direct comparison with the Pingvin and/or another compression garment affecting
2 performance (34-35) would provide a more appropriate comparative model.

3 The ability to perform resistance exercise was not significantly impeded by wearing the
4 GLCS in the majority of the exercises performed. However, difficulties were encountered
5 when performing the shoulder press, with three individuals unable to complete the prescribed
6 3 sets of 12 reps whilst maintaining adequate control. This could be attributed to increased
7 effort required by the participant to overcome the loading provided by the GLCS during the
8 standing shoulder press. Whether this additional effort provides a useful adjunct to resistance
9 exercise would require further study, including an assessment of muscle activity. However,
10 all subjects did report that for the same exercise load (GLCS vs. GYM), wearing the GLCS
11 increased the perceived effort. Thus, the axial loading provided by the GLCS, if adjusted to
12 the appropriate level, might provide a training stimulus across a range of joints and, in
13 postures appropriate to the individuals' requirements and capabilities, offering a potential
14 physiological/training augmentation strategy for use in microgravity and terrestrial settings,
15 as reported with the use of whole body compression garments in male athletes (35).

16 A main limitation of this study is the small, gender unbalanced sample size and therefore
17 more data from additional gender matched groups should be investigated further. Loading
18 also needs to be reassessed with integrated force sensors in the shoes, during different body
19 positions both whilst in contact with the ground and when floating in microgravity, to more
20 accurately capture the axial load produced by the GLCS. The characterisation of loading
21 should also be performed during the exercise, along with measurements of muscle activity
22 and exercise response, as predominantly only subjective measures of performance during
23 exercise were assessed in this first trial. This could then determine if additional axial load
24 during exercise is effecting muscle recruitment, as this could have intriguing applications for

1 modifying training response. However further refinements to the GLCS are suggested to
2 improve comfort, tolerability and the ability to don and doff the garment with ease, as this
3 was an issue for several participants.

4 This approach of combined wear with exercises such as running and task specific body
5 weight exercises could be investigated to determine if additional axial loading augments
6 athletic training in healthy populations. Additional axial loading in the future may also aid to
7 provide a stimulus for to support bone fracture healing (36) and rehabilitation from musculo-
8 skeletal degradation induced by disuse, disease or injury (7,37) after further investigation.

9

10 **PRACTICAL APPLICATIONS**

11 The GLCS demonstrates potential as a lightweight, low volume/cost countermeasure against
12 the loss of axial loading in microgravity, by providing static axial loading broadly analogous
13 to Earth. Such axial loading has minor effects on ambulation and range of motion and renders
14 strength exercise 12 repetition maximum completions more challenging, without apparent
15 thermal issues. With the growing rise of smart clothing in athletic disciplines, loading suits
16 primarily designed for use in space may have potential terrestrial benefit as either training
17 augmentation or rehabilitation tools; however more research is required in this area. Thus the
18 GLCS, with further design improvements and future investigations, may provide a useful
19 adjunct to exercise, potentially either by providing a complimentary training modality or
20 through virtue of its static loading, assist in ameliorating musculoskeletal deconditioning
21 associated with space, disuse or injury.

22

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8

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Table 1. Mean (\pm SEM) maximal ambulation angle ($^{\circ}$) achieved in the GLCS and GYM clothing. * significant difference ($p < 0.05$).

Condition	Shoulder Flexion ($^{\circ}$)	Shoulder Extension ($^{\circ}$)	Spinal Flexion at Yoke ($^{\circ}$)	Spinal Extension at Yoke ($^{\circ}$)	Spinal Flexion at T12 ($^{\circ}$)	Spinal Extension at T12 ($^{\circ}$)
GYM	183 \pm 6	65 \pm 4	143 \pm 5	33 \pm 3	82 \pm 3	33 \pm 3
GLCS	149 \pm 8*	51 \pm 9	105 \pm 7*	21 \pm 6*	56 \pm 3*	11 \pm 1*
	Hip Abduction ($^{\circ}$)	Hip Adduction ($^{\circ}$)	Knee Flexion ($^{\circ}$)	Knee Extension ($^{\circ}$)	Sit and Reach (cm)	Get up and Go (s)
GYM	60 \pm 7	26 \pm 3	113 \pm 4	12 \pm 1	27.7 \pm 3.2	4.9 \pm 0.1
GLCS	48 \pm 6*	26 \pm 5	100 \pm 3*	11 \pm 1*	14.9 \pm 2.6*	5.6 \pm 0.2*

Table 2. Mean (\pm SEM) number of final (3rd) set repetitions, average time to completion of sets (s) and delta core body temperature ($^{\circ}$ C) in the GLCS and GYM clothing. * significant difference ($p < 0.05$)

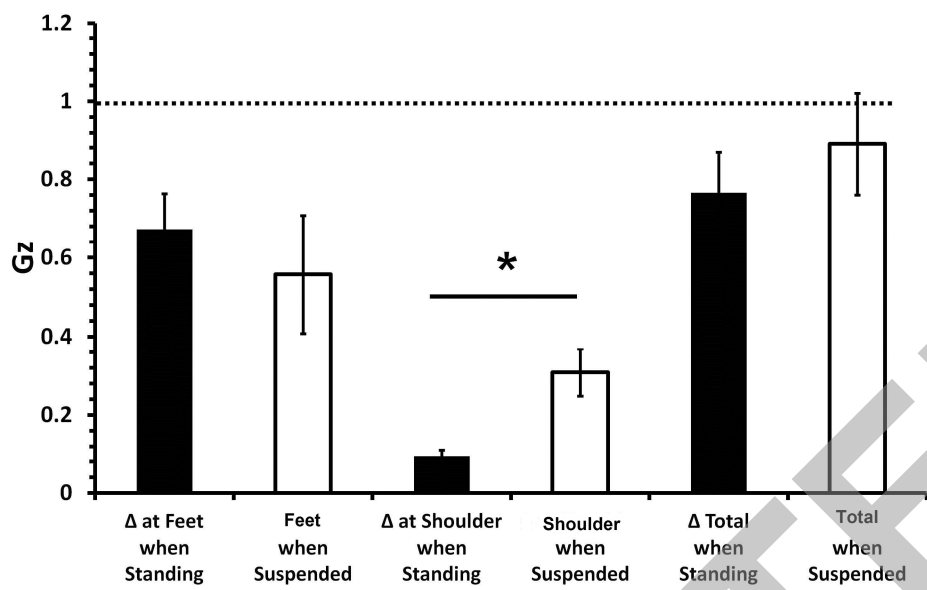
Number of Reps completed	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	12 \pm 0	12 \pm 0	12 \pm 0	12 \pm 0	12 \pm 0	12 \pm 0
GLCS	9 \pm 3*	12 \pm 0	12 \pm 0	12 \pm 0	12 \pm 0	12 \pm 0
Average time to completion (s)	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	30.4 \pm 4.9	30.1 \pm 7.8	24.1 \pm 6.4	24.1 \pm 6.4	29.3 \pm 6	21.3 \pm 6
GLCS	26.3 \pm 3.8*	27.5 \pm 8.1	26.5 \pm 9.1	23.2 \pm 8.3	30.9 \pm 9.5	18.5 \pm 5.2
Δ Temperature ($^{\circ}$C) Pre – End of 3rd set	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	0.2 \pm 0.2	0.1 \pm 0.1	0.1 \pm 0.1	-0.1 \pm 0.1	0.1 \pm 0.2	0.1 \pm 0.1
GLCS	0.1 \pm 0.1*	0.1 \pm 0.2	0.1 \pm 0.1	0.1 \pm 0.1	0.1 \pm 0.1	0.1 \pm 0.1

Table 3. Median (interquartile range) Movement Discomfort and Body Control Ratings at the end of the final (3rd) set of strength exercise in the GLCS and GYM clothing. * significant difference ($p < 0.05$).

Movement Discomfort	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	2 (2.0-2.0)	2 (2.0-2.0)	2 (2.0-2.3)	2 (2.0-2.0)	2 (2.0-2.3)	2 (2.0-2.0)
GLCS	8* (6.5-9.0)	7* (5.0-9.0)	6* (5.0-8.3)	5.5* (5.0-8.0)	5.5* (4.0-9.0)	5* (5.0-6.0)
Body Control	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	2 (2.0-2.0)	2 (2.0-2.3)	2 (2.0-2.3)	2 (2.0-2.0)	2 (2.0-2.0)	2 (2.0-2.0)
GLCS	7* (5.8-8.0)	6* (5.8-7.0)	5* (4.8-6.3)	5* (4.8-6.3)	5* (4.8-7.0)*	5* (4.8-6.0)

Table 4. Median (interquartile range) Rating of Perceived Exertion (RPE) and Thermal Comfort at the end of the final (3rd) set of resistance exercise in the GLCS and GYM clothing. * significant difference (p<0.05)

Rating of Perceived Exertion (RPE)	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	15 (13.8-15.8)	15 (13.8-15.5)	15 (14.8-15.8)	15 (14.8-16.0)	15 (14.8-16.3)	13.5 (13.0-14.3)
GLCS	16 * (15.0-19.0)	15.5 (13.8-17.3)	15 (14.0-15.5)	15 (14.0-15.5)	16 (15.5-19.0)	15 (13.8-15.0)
Thermal Comfort	Shoulder Press	Squat	Chest Press	Seated Row	Leg Press	Calf Raise
GYM	+2 (1.0-2.0)	+2 (1.8-2.0)	+2 (1.0-2.0)	+2 (1.8-2.0)	+2 (2.0-2.0)	+2 (1.0-2.0)
GLCS	+1 (0.8-1.3)	+2 (1.0-2.3)	+2 (2.0-3.0)	+1.5 (1.0-2.0)	+2 (2.0-3.0)	+1.5 (1.0-2.0)



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