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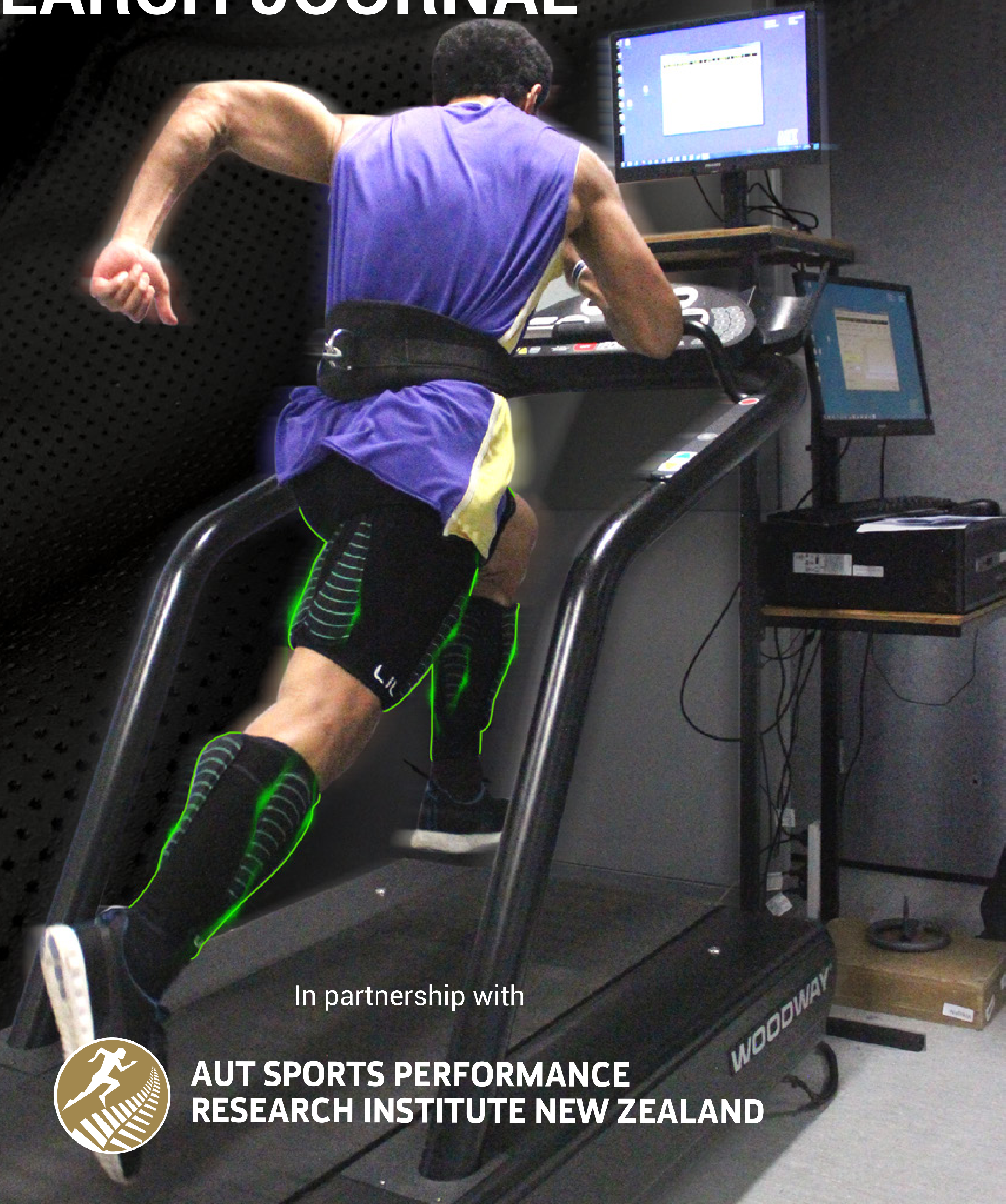
WEARABLE RESISTANCE RESEARCH JOURNAL



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How to Use this Document

The document contains summaries of all peer-reviewed publications to date related to LILA EXOGEN (wearable resistance). Summaries include research title and citations, background information, brief description of the methods, key findings, and practical applications. Articles are organized by primary sport/activity of interest.

Purpose

The main reason of conducting the research; what question was trying to be answered.

Introduction/Background

This section provides a brief description of any background knowledge that may be relevant to the research study. This could include previous literature and findings, as well as the authors' hypotheses. This section also provides a brief description of the methods that were used in the research. This may include how the research was conducted, what occurred during data collection, what technologies and analyses were used, and any other pertinent information in regards to the actual data collection and analysis process.

Key Findings

This section provides the key findings of the research. These key findings are non-biased, with objective results only.

Practical Applications

This section provides practical applications; how coaches and athletes may use this research in their own practice. These practical applications are based on the objective key findings, as well as both the researchers' subjective knowledge. Coaches, athletes, and the like are encouraged to read the full research publication and draw their own conclusions.

Important Note: All references are cited at the end of this document in the References Section. Full-text publications can and should be referred to for more information.

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Literature Review

Systematic Review: Acute and longitudinal effects of weighted vest training on sprint performance

Macadam, Cronin (1)

Purpose Statement:

Review the literature to attempt to quantify the acute and longitudinal effects of weighted vests during sprinting.

Introduction:

A systematic search of literature (vest OR trunk AND sprint* AND (resist* OR weight OR load*)) found 11 studies to be included in the review. Subjects ranged from sedentary populations to competitive athletes, with vests loads from 5% to 40% BM. Six acute and 5 longitudinal studies were analyzed to identify the mechanistic determinants of changes that occur in sprinting, any improvements in sprint speed, and the critical loading parameters for these changes.

Key Findings:

1. Acute effects of 5-40% BM vest loading increased sprint times from 10m to 50m
2. Acute vest loading (5% to 21.9% BM) during treadmill running effected contact times (increased 3.8%-9.2%) and flight times (decreased 15% to 26.7%) more than step frequency and length, with greater changes during the maximum velocity phase than the acceleration phase.
3. VGRF was significantly decreased with 5% BM, unaffected with 10.9% BM, and increased with 21.8% BM.
4. All weighted vest longitudinal studies reported improvements in velocity and sprint times (8 days to 7 weeks of training); however not all were statistically significant.

Practical Applications:

1. Weighted vest loading may have a greater effect on sprint performance during the maximum velocity phase rather than the acceleration phase
2. Loads >10% BM may be required to significantly decrease vertical ground reaction forces.
3. The maximum velocity phase of sprint running may be more sensitive to vertical loading with vests loads due to the importance of vertical force production in producing maximum velocity sprinting.
4. Large variations in study methodologies make it inappropriate to formulate conclusions on the long-term effects of weighted vests on sprint performance

Literature Review: Effects of different wearable resistance placements on sprint-running performance: A review and practical applications

Macadam, Cronin (2)

Purpose Statement:

Review the literature on the effects of wearable resistance and placement on sprint-running performance during the acceleration and maximum velocity phases.

Introduction:

Wearable resistance enables athletes to perform movement-specific resisted training, aligning with the concept of specificity, and important factor when prescribing sprint training programs. A search (wearable resistance, weighted vest, limb loading, trunk loading, external loading, resisted sprinting, inertia loading, added mass, spring, acceleration, and velocity) of peer-reviewed journal articles and conference papers were found from a multitude of online databases. A total of 20 studies were included in the review: 4 studies loading the arm, 9 studies loading the trunk, and 9 studies loading the lower body. Acute and longitudinal studies used subjects from sedentary subjects to national beach sprinters. Loading ranged from 0.6% BM to 21.8% BM.

Table 1: Summary of effects of WR loading and placement on sprinting variables during the acceleration phase

Table 6
Summary of acute and longitudinal changes to kinematic and kinetic variables with different wearable resistance placement and magnitudes during the acceleration phase of sprint running

% body mass	Sprint times (<20 m)	SL	SF	CT	FT	Vo	Fo	Pmax	F-v	VGRF	HGRF
Arm											
≤1%		=	=			=					
>1–2%		=	=			=					
≥2%	↑ ≥10 m	↑	↓	↑	↓	↓	=	↓	=		
Trunk											
≤5%	= treadmill, ↑ overground	=	=	=	↓	=		=		=	=
>5–10%	↑					==					
≥10–15%	↑			↑	↓	↓	↓	=		=	=
	==	==	==	==	==						
≥15–20%	↑			↑	↓						
	⇣	==									
≥20%				↑	↓	↓	↓	=		↑ Mean	=
Leg											
>1–2%	=	=	↓	↑	=	↓					
≥2–3%	=	=	=	↑	=	↓					
		⇡	⇣			==					
≥3–4%	=	=	↓	↑	=	↓	=	=	↑		
≥4%	↓ ≥15 m	=	↓	↑	=	↓	=	=	=	↑	=

↑ : acute study; ⇡ : longitudinal study; = : no significant acute change, ==: no significant longitudinal change, ↓ Significance $p < 0.05$.

CT, contact time; Fo, maximum horizontal force; FT, flight time; F-v, force–velocity slope; HGRF, horizontal ground reaction force; Pmax, maximum horizontal power; SF, step and stride frequency; SL, step and stride length; VGRF, vertical ground reaction force; Vo, maximum velocity.

Table 2: Summary of effects of WR loading and placement on sprinting variables during the maximum velocity phase

Table 7
Summary of acute and longitudinal changes to kinematic and kinetic variables with different wearable resistance placement and magnitudes during the maximum-velocity phase of sprint running

% body mass	Sprint times (≥20 m)	SL	SF	CT	FT	Vo	Fo	Pmax	F-v	VGRF	HGRF
Arm											
≤1%		=	=			=					
>1–2%		=	=			↓					
≥2%	↑					↓	=	↓	=		
		⇑	⇓			==					
Trunk											
≤5%	= treadmill, ↑ overground	=	=	↑	=	=		=		= rel	=
>5–10%	↑										
≥10–15%	↑	↓	=	↑	↓	↓		=		=	=
	==	==		⇑	==						
≥15–20%	↑										
	⇓ 30 m	==	==	==	==	==					
	== > 30 m										
≥20%		↓	↓			↓		↓		↑ Mean	=
Leg											
≤1%		↑	↓	↑	↑	↓					
>1–2%		=	↓	↑	=	↓					
≥2–3%	↑ whole leg	=	↓ thigh	↑ thigh	↑ shank	↓					
	= thigh		= whole leg	↑ shank	= whole leg						
	= shank		= shank	= whole leg	= thigh						
			⇑	⇓							
≥3–4%							=	=	↑		
≥4%	↑	=	↓	↑	=	↓		=		↑	=

↑ : acute study; ⇑ : longitudinal study; = : no significant acute change, ==: no significant longitudinal change, ↓ Significance $p < 0.05$.

CT, contact time; Fo, maximum horizontal force; FT, flight time; F-v, force–velocity slope; HGRF, horizontal ground reaction force; Pmax, maximum horizontal power; SF, step and stride frequency; SL, step and stride length; VGRF, vertical ground reaction force; Vo, maximum velocity.

Key Findings:

1. Small magnitudes (~2% BM) provide sufficient overload during limb loading, while greater magnitudes are required during trunk loading (>10% BM)
2. Acute and longitudinal increases in step and stride length and decreases in step and stride frequency from arm loading (.6% to 2.5% BM)
3. Trunk loading >20% BM increased VGRF (~8%), however trunk loading ~5% BM decreased VRGF (~6%) during max velocity sprinting
4. Whole leg loads of <3% BM, thigh or shank <2%, and ankle loads <1,6% significantly decreased velocity and step and stride frequency during sprinting, combined with no significant change in step and stride length (<5% BM).

Practical Applications:

1. Trunk loading allows greater wearable resistance to be added, without direct overload to the limbs, resulting in less change in step length and step frequency.

2. Arm WR overload may provide a suitable method for cueing and improving arm drive mechanics during sprinting, particularly during the early acceleration phase.
3. Trunk WR may increase the sprinters ability to produce greater GRF and power, and may an appropriate overload for vertical stiffness to target reactive strength development during maximum velocity sprinting
4. Lower body WR may provide non-verbal training cues for improved sprint mechanics and encourage a more horizontal GRF application

Systematic Review: Effects of lower limb wearable resistance on sprint running

Feser, Macadam (3)

Purpose Statement:

Evaluate the literature that has used lower limb wearable resistance during sprint running.

Introduction:

A specific concern with resisted sprint training is that the added load can unfavorably changes sprint kinematic variables such as stride/step length, ground contact times, and stride/step frequency. A systematic search found 10 studies with 116 subjects that completed a sprint running intervention with lower limb WR; 8 studies investigating acute effects on movement kinematics, 4 studies loaded the entire leg (thigh and shank), 2 studies only using thigh or shank loading, and 1 study loading the ankle. Micro-loading ranged from 0.6% to 5% BM. Only 1 longitudinal training study was reviewed, loading the ankle at 5% BM for 6 weeks.

Key Findings:

1. Joint kinematics are minimally affected when sprint running with an added 5% BM load on the lower limbs.
2. All studies found running velocity was affected as a result of the concomitant change in stride rate, not stride length.
3. 3% BM lower limb loading was found to elicit moderate changes (10.0 - 11.0%, ES=0.62 - 0.72) to the relative F-V profile (more force dominant).
4. 5% BM lower limb WR may not overload the system enough to provoke greater vertical force production values during maximal velocity running; however, there was a significant increase in mean vertical ground reaction force values that were produced during the acceleration phase.

Practical Applications:

1. If looking to overload the start phase, practitioners may utilize higher loads (deemed comfortable) to induce a greater loading stimulus.
2. 3% BM lower limb WR may provide a stimulus to increase horizontal force output during 20m sprints, which may have the potential to elicit improved sprinting performance over time through greater horizontal force production.
3. To target increase forced production through the maximal velocity phase of sprinting, likely that loads greater than 5% NBM are needed to overload the vertical system.
4. The effect of a given WR load varies for each phase of sprint running, and thus may be used to target certain aspects of sprint running.
5. Practitioners should take care to progressively overload the athletes, especially during the beginning of the training season, to reduce possible risk of injury.

Jumping

Acute Study: Acute kinematic and kinetic adaptations to wearable resistance during vertical jumping

Macadam, Simperingham (4)

Purpose Statement:

To compare the effects of different WR placements and magnitudes on vertical jump performance.

Introduction:

WR of 3% or 6% BM, attached to either the upper body and lower body (Figure 1), was used to assess the acute effects on CMJ, DJ and pogo jump performance in recreational trained/ sport science student subjects (10 males and 10 females). Loads were evenly distributed for upper body loading, and for lower body, 2/3rd of the load placed evenly around the thigh and the remaining 1/3rd on the shank of the leg.

Figure 1: Upper and lower body WR

Key Findings:

1. Acute significant decreases in jump height (-10% to -17%) were found in CMJ & DJ, due to reduced peak power (-7% to -17%) and peak velocity (-3% to -8%).
2. No significant effect on landing ground reaction force (GRF) with any condition.
3. Acute significant increases in contact time (7.9-9.7%) and decreases in flight time (-7.7% to -8.2% with 6% BM only) resulted in significantly decreased reactive strength index (-16.9% to -21.4%) in pogo jumping.

4. Greater acute decreases found in lower than upper body WR, but no significant difference between conditions.

Practical Applications:

1. Safely overload athletes up to 6% BM without increasing landing GRF with either upper or lower body WR.
2. Given stability of force measure and velocity decrement, athletes should focus on velocity of movement to improve power output and jump height i.e. CMJ take-off velocity.
3. May enhance SSC performance in DJ and PJ due to overload requiring extensor strength to reduce contact time and improve flight time and stiffness.
4. Improved specificity of training was theorised as WR was proposed to be less likely to alter the jump flight path compared to barbell or dumbbell loading.

Training Study: Redistributing load using wearable resistance during power clean training improves athletic performance

Marriner, Cronin (5)

Purpose Statement:

To investigate how power clean training with WR over a 5-week period effects lower CMJ performance in resistance trained males.

Introduction:

WR of 12% attached to the posterior of the upper and lower body (Figure 2) was used to assess the longitudinal effects on the CMJ performance following a 5-week power clean training study. Two groups of eight recreational trained males completed power cleans either with the load redistributed from the bar to the body via WR, or via traditional power clean training. Both groups performed three supervised power clean training sessions per week, following an undulating periodisation model.

Figure 2: Posterior upper and lower body WR of 12% BM

Key Findings:

A significant increase in CMJ height (4.2%) was found compared to a decrease for the control group (-1.4%), following a 5-week power clean training study (Table 3).

Table 3: Pre to post changes for CMJ

	TR group				12% BM WR group					
Performance measures	Pre	TE	Post	Change in mean scores	Pre	TE	Post	Change in mean scores	Net effect ± confidence limits	ES: Mechanistic inference

CMJ height (cm)	41.7 ± 4.9	4.82	41.1 ± 2.4	-0.58 ± 3.9	37.1 ± 8.2	0.9	40.6 ± 8.8	3.52 ± 1.5	4.1 ± 2.8	0.53: Likely ↑

↑ - Beneficial effect or increase. ES = effect size, TE = typical error, TR = traditional loading

Practical Applications:

Power clean training with compensatory WR would seem a better training method to improve jump height and functional lower body power production.

Running

Acute Study: Effects of upper and lower body wearable resistance on spatio-temporal and kinetic parameters during running

Couture, Simperingham (6)

Purpose Statement:

This study compared the effects of different WR placements on steady state treadmill running performance.

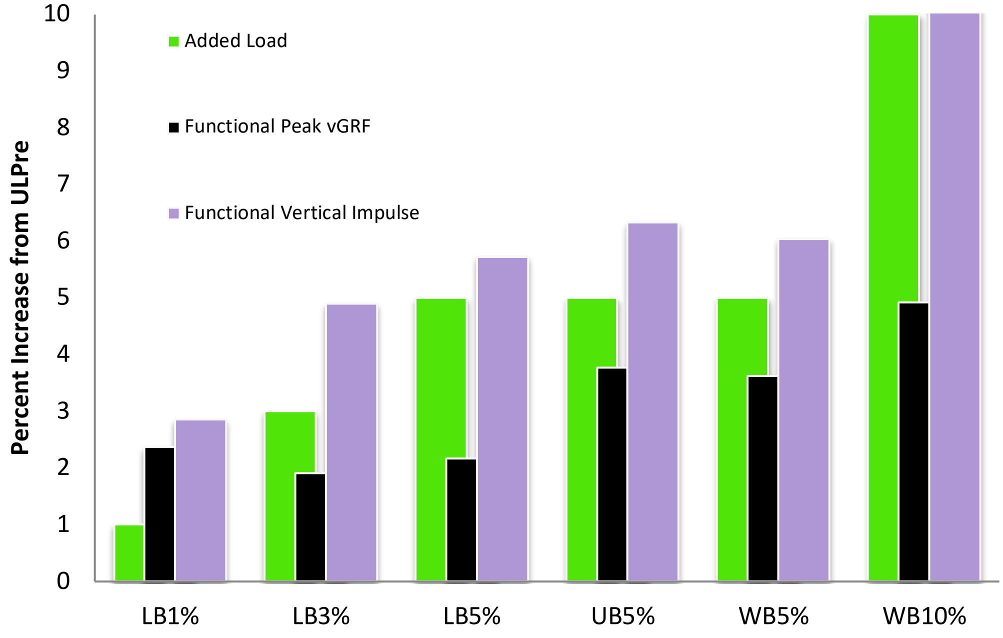
Introduction:

WR of 1-10% BM was attached to either the upper, lower, or whole-body (Figure 1) during treadmill running (3.9 m/s). Twelve recreational trained/ sport science student subjects were randomly assigned to five minutes of treadmill running with each WR condition: 1% BM lower body. 3% BM lower body, 5% BM lower body, 5% BM upper body, 5 % BM whole body, 10% BM whole body.

Key Findings:

1. 5% BM and greater WR loads caused significant changes in vertical stiffness, vertical and horizontal force, and impulse.
2. Functional and effective propulsive force (3.0%, 2.8%) and impulse (2.9%, 3.5%) were significantly greater with lower 5% BM than upper 5% BM.
3. The lower body 5% BM (2.2%) and whole body 10% BM (4.9%) conditions resulted in the lowest relative increase in functional peak vGRF compared to increase in BM (Figure 3).
4. Only significant spatiotemporal change was to contact time, which increased (2.9%) with whole body 10% BM.
5. Heart rate was significantly greater with all WR conditions (5.4-8.8%) and RPE significantly greater with lower 5% BM (27.9%) and whole body 10% BM (32.6%).

Figure 3: A comparison of percent increase in functional vertical impulse and functional peak vGRF



Practical Applications:

1. WR may be used to increase forces and muscular stimulus without negatively effecting normal running gait.
2. A runner with an overly “bouncy” stride (excessive vertical motion), may benefit from lower body WR to increase horizontal force.
3. A runner with a long, low stride may benefit from upper body WR to increase vertical force and balancing out the trajectory may be more beneficial.

Acute Study: Acute metabolic changes with thigh-positioned wearable resistances during submaximal running in endurance-trained runners

Field, Gill (7)

Purpose Statement:

Investigate how a magnitude of between 1% and 5% BM WR attached to the thigh affects the acute metabolic responses to submaximal running in endurance trained runners

Introduction:

In recreational distance runners, heavy resistance, explosive resistance and muscle endurance resistance training have been found to significantly improve running performance. At elite levels, concepts of progressive overload and specificity become more important. Twenty endurance-trained runners performed four sessions (Figure 4); familiarization and three testing sessions on a motorized treadmill with different thigh loading schemes (0% [unloaded], 1%, 2%, 3%, 4%, 5%). Metabolic response measures of HR response, oxygen consumption (VO_2), lactate accumulation (LA), training load score (TLS)(combination of avgHR, intensity factor, VT_2 - point which LA accumulation exceeds clearance), and rate of perceived exertion (RPE).

Figure 4: Structure of Testing Sessions

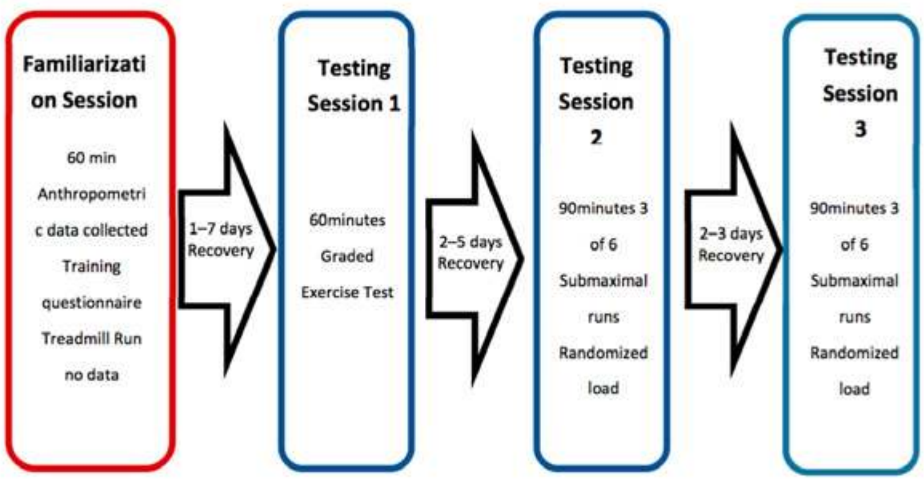


Figure 3. Structure of the testing sessions.

Key Findings:

1. There is an expected 1.59% (± 0.62) increase in VO_2 for every 1% BM of additional thigh load
2. There is an expected 0.63% (± 0.32) increase in acute HR for every 1% BM of additional thigh load
3. Loads at 3% and 4% BM reported very likely large increases in lactate accumulation (0.41 ± 0.18 and 0.42 ± 0.19 respectively) with mean accumulations of 3.27 (±1.79) and 3.30 mmol/L (±2.03) respectively and most likely very large increase at 5% BM (3.52 mmol/L)(Figure 5)

4. Both 4% and 5% BM reported most likely very large increases in RPE (0.82 ± 0.29 and 0.86 ± 0.28 respectively), with mean reported scores of 4.20 (±1.26) and 4.38 (±1.57) respectively (Figure 5)

Figure 5: Lactate Accumulation and Rate of Perceived Exertion (0% - 5% BM)

Table 3. Acute Lactate responses to thigh wearable resistances.

Training Load (%BM)	Mean LA (mmol/L)	Effect Size (±90% CI)	Rating
0%	2.62 ± 1.56	-	-
1%	2.77 ± 1.90	0.0 (−0.27; 0.28)	(12/77/11) unclear effect
2%	4.83 ± 2.04	0.08 (−0.07; 0.23)	(10/90/0) likely trivial increase
3%	3.27 ± 1.79	0.41 (0.23; 0.60)	(97/3/0) very likely large increase
4%	3.30 ± 2.03	0.42 (0.23; 0.61)	(97/3/0) very likely large increase
5%	3.52 ± 2.35	0.49 (0.34; 0.63)	(100/0/0) most likely very large increase

Abbreviations: BM, body mass; CI, Confidence interval. The values are mean blood LA accumulations sampled immediately post 8 min of submaximal treadmill running at the first ventilatory threshold.

Table 4. Acute rate of perceived exertion responses to thigh wearable resistances.

Training Load (%BM)	Mean Rate of Perceived Exertion	Effect Size (±90% CI)	Rating
0%	3.08 ± 1.37	-	-
1%	3.35 ± 1.16	0.28 (0.03; 0.53)	(70/30/0) possible small increase
2%	3.68 ± 1.44	0.43 (0.19; 0.66)	(95/5/0) likely moderate increase
3%	3.73 ± 1.33	0.52 (0.26; 0.78)	(98/2/0) very likely large increase
4%	4.20 ± 1.26	0.82 (0.53; 1.11)	(100/0/0) most likely very large increase
5%	4.38 ± 1.57	0.86 (0.58; 1.14)	(100/0/0) most likely very large increase

Abbreviations: BM, body mass; CI, Confidence interval. The values are mean RPE scores recorded immediately post 8 min of submaximal treadmill running at the first ventilatory threshold.

Practical Applications:

1. Limb loading during locomotion can increase metabolic cost compared to unloaded
2. When WR is attached to the thighs, great VO_2 changes occur compared to trunk placement, most likely due to greater inertial demands from distal thigh loading
3. Loads of at least 2% and 3% BM are needed to see substantial increases in HR and VO_2 responses.
4. WR attached to the legs enable a running-specific form of resistance training to be incorporated into training programming

Acute Study: Acute metabolic changes with lower leg-positioned wearable resistances during submaximal running in endurance-trained runners

Field, Gill (8)

Purpose Statement:

Investigate how a magnitude of between 0% to 2.5% BM WR attached to the calf affects the acute metabolic responses to submaximal running in endurance trained runners

Introduction:

In recreational distance runners, heavy resistance, explosive resistance and muscle endurance resistance training have been found to significantly improve running performance. At elite levels, concepts of progressive overload and specificity become more important. Twenty endurance-trained runners performed four sessions (Figure 4); familiarization and three testing sessions on a motorized treadmill with different calf loading schemes (0% [unloaded], 0.5%, 1.0%, 1.5%, 2%, 2.5%). Metabolic response measures of HR response, oxygen consumption (VO_2), lactate accumulation (LA), training load score (TLS)(combination of avgHR, intensity factor, VT_2 - point which LA accumulation exceeds clearance), and rate of perceived exertion (RPE).

Figure 6: Structure of Testing Sessions

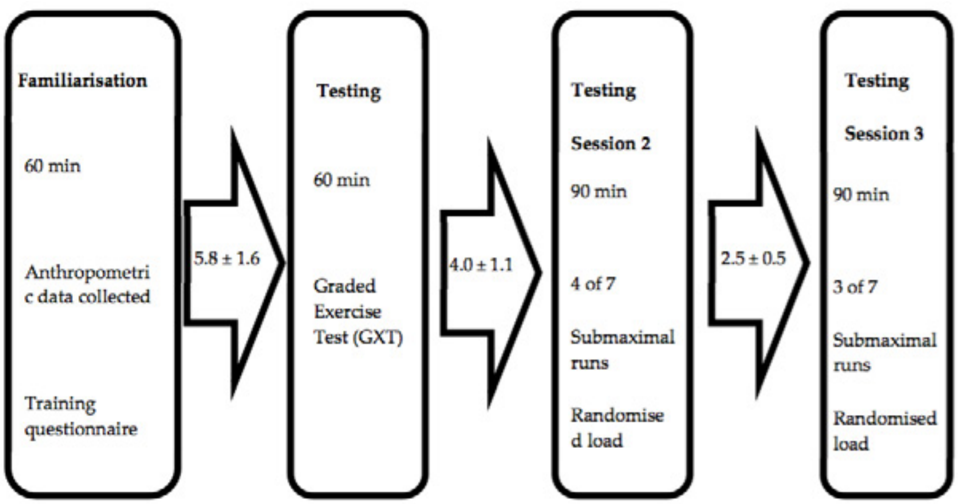


Figure 7: Example of lower-leg wearable resistance loading pattern (0.5%) for a 70kg runner

Figure 8: Example of lower-leg wearable resistance loading pattern (1.5%) for a 70kg runner

Figure 9: Example of lower-leg wearable resistance loading pattern (2.5%) for a 70kg runner

Key Findings:

1. There is an expected 2.56% (± 0.75) increase in VO_2 for every 1% BM of additional calf load
2. There is an expected 1.16% (± 0.52) increase in acute HR for every 1% BM of additional calf load
3. There is an expected 0.39% (± 0.06) increase in exercise stress for the equivalent of 10-min of running for every 1% BM of additional calf load
4. There were most likely very large increases in both acute lactate accumulation and RPE with 2.5% and greater BM of calf loading

Figure 10: Lactate Accumulation and Rate of Perceived Exertion (0% - 5% BM)

Training Load (% BM)		0% BM	0.5% BM	1.0% BM	1.5% BM	2.0% BM	2.5% BM	3.0% BM
Acute Oxygen Consumption (VO_2)(L)	Mean (SD)	3.22 (0.48)	3.28 (0.53)	3.36 (0.59)	3.39 (0.56)	3.39 (0.53)	3.43 (0.59)	3.52 (0.54)
	Effect Size (90% CI)	-	0.09 (-0.02 to 0.19)	0.22 (0.9 to 0.34)	0.28 (0.17 to 0.39)	0.3 (0.19 to 0.40)	0.34 (0.22 to 0.44)	0.51 (0.42 to 0.60)
	Rating	-	Very likely trivial increase	Possible small increase	Likely moderate increase	Likely moderate increase	Very likely large increase	Most likely very large increase
Acute HR (bpm)	Mean (SD)	150.2 (10.2)	151.6 (9.09)	153.5 (12.1)	154.1 (12.1)	155.5 (9.84)	156.7 (9.17)	156.8 (7.95)
	Effect Size	-	0.13 (-.06 to 0.33)	0.30 (0.8 to 0.52)	0.35 (0.19 to 0.52)	0.49 (0.19 to 0.40)	0.60 (0.44 to 0.76)	0.62 (0.4 to 0.84)
	Rating	-	Possible small increase	Likely moderate increase	Likely moderate increase	Most likely very large increase	Most likely very large increase	Most likely very large increase
Acute Lactate (La mmol/L)	Mean (SD)	1.89 (0.60)	2.29 (0.89)	2.35 (0.72)	2.37 (1.11)	2.44 (0.95)	2.61 (0.66)	2.83 (1.22)
	Effect Size	-	0.49 (0.3 to 0.95)	0.63 (0.22 to 1.03)	0.45 (-.03 to 0.93)	0.65 (0.12 to 1.19)	0.96 (0.52 to 1.39)	1.05 (0.6 to 1.51)
	Rating	-	Likely moderate increase	Very likely moderate increase	Likely moderate increase	Likely moderate increase	Most likely very large increase	Most likely very large increase
Acute RPE	Mean (SD)	2.53 (0.88)	3.03 (1.22)	3.27 (1.07)	3.40 (1.02)	4.00 (1.28)	4.3 (1.15)	4.53 (1.59)
	Effect Size	-	0.40 (0.07 to 0.72)	0.63 (0.35 to 0.90)	0.73 (0.35 to 1.11)	1.11 (0.78 to 1.43)	1.30 (1.05 to 1.55)	1.38 (0.98 to 1.79)
	Rating	-	Likely moderate increase	Very likely moderate increase	Very likely moderate increase	Most likely very large increase	Most likely very large increase	Most likely very large increase

Practical Applications:

1. Limb loading during locomotion can increase metabolic cost compared to unloaded
2. When WR is attached to the calves, great VO_2 changes occur compared to trunk placement, most likely due to greater inertial demands from distal thigh loading

3. Loads of at least 2% and 3% BM are needed to see substantial increases in HR and VO_2 responses.
4. WR attached to the legs enable a running-specific form of resistance training to be incorporated into training programming

Sprinting

Acute Study: Changes in sprint kinematics and kinetics with upper body loading and lower body loading using EXOGEN® Exoskeletons

Simperingham and Cronin (9)

Purpose Statement:

To compare the effects of different WR placements on maximal sprinting performance using a non-motorised treadmill.

Introduction:

WR of 5% BM was attached to either the upper and lower body (Figure 11). Eight sport science students performed four sets of two 6 second sprints on a non-motorised treadmill.

Figure 11: Lower and upper body WR

Key Findings:

1. For the same relative load (5% BM), greater changes with lower body WR were found compared to upper:
    a. the time to cover distances above 10 m and the peak velocities achieved during AP and MVP were significantly slower by -2.3 to -4.2 % with lower WR
    b. lower WR resulted in a - 2.9 % reduction in step frequency during acceleration
2. Lower body WR loading resulted in increased vertical GRF (up to 5%), while altering peak velocity, contact time and step frequency (< 5 %).

3. Upper body WR did not alter velocity but reduced FT up to 15% and consequently decreased vertical GRF relative to BM (up to 6 %).
4. 7 out of 8 participants perceived improved unloaded sprint performance following four sprints with WR.

Practical Applications:

1. Lower body loading rather than upper body loading at 5% BM appears to provide a more effective vertical stimulus to increase eccentric strength and muscle stiffness.
2. For athletes wanting to overload the start and acceleration phase of a sprint, lower body loading may be used to increase GRF and step variables.
3. A series of sprints with WR may be an effective pre-conditioning stimulus to induce a perception of potentiated unloaded sprint acceleration performance.

Acute Study: Acute changes in sprint running performance following ballistic exercise with added lower body loading

Simperingham, Cronin (10)

Purpose Statement:

To compare the effects of different WR magnitudes during loaded warm-ups on over ground sprint performance.

Introduction:

WR of 1, 3 and 5% BM was attached to the lower body to assess the effects of different loaded warm-ups on sprinting (Figure 12). One male athlete performed three unloaded 40 m over the ground sprints following different ballistic warm-up methods with WR. Each condition was performed on a separate day.

Figure 12: Thigh and shank WR

Key Findings:

1. The loaded accelerations and loaded warm-up resulted in longer contact time (3-4%) during initial acceleration, enabling more time for horizontal force application, lower step frequency (-1 to -3%) during acceleration and a substantial acute improvement in sprint performance.
2. Overloading the vertical force pattern with drop jumps and the more upright flying sprints did not result in a change in sprint acceleration performance.

Practical Applications:

Lower body WR 3% BM worn during a dynamic speed warm-up 40 m accelerations appears to be effective at acutely improving subsequent unloaded sprint at 10, 30 and 40 m performance, perhaps by providing a non-verbal cue for improved lower limb sprint mechanics.

Acute Study: Changes in acceleration phase sprint biomechanics with lower body wearable resistance

Simperingham, Cronin (11)

Purpose Statement:

How do different WR loads of the whole leg effect 20 m sprint performance.

Introduction:

Fifteen male amateur rugby players performed three 20 m over the ground sprints with either WR of 3% or 5% BM whole leg loading.

Key Findings:

1. No significant changes in sprint times over 10 m with either load but the 20 m sprint time with 5% loading was significantly slower than unloaded (-2%) and 3% condition (-1%).
2. Significant decrease in theoretical maximum velocity (V_0) (-5 to -6%) with both loads and non-significant increase in theoretical horizontal force production (F_0) (4%) but only with 3% BM.
3. Theoretical maximum horizontal power output (Pmax) increased with 3% BM (1.2%, $p > 0.05$) compared to unloaded, though 5%BM WR was significantly decreased (-4.2%) compared to the 3%BM condition.
4. Significant changes to contact time (4.3-4.5%) and step frequency (-1.7-2.6%). No significant changes to step length or flight time.

Practical Applications:

1. 3% BM WR serves to increase horizontal force output during the acceleration phase of sprinting and may be suitable for athletes seeking to improve horizontal force and power during sprint acceleration.
2. Athletes can be safely loaded up to 5% BM without substantially altering sprint mechanics.
3. No change in sprint time at 10m with either load, therefore, >5%BM may be needed to overload the early acceleration phase.

Acute Study: Acute kinematic and kinetic adaptations to wearable resistance during sprint acceleration

Macadam, Simperingham (12)

Purpose Statement:

How do different WR placement of the whole leg effect 20 m sprint performance.

Introduction:

Nineteen amateur to semi-professional rugby males performed two 20 m over the ground sprints unloaded and with each WR condition: 3% BM either attached to the anterior or posterior surface of the lower body (Figure 13).

Figure 13: WR of 3% BM: Anterior and Posterior Positions

Key Findings:

1. No significant decrease in time over 20 m, but significant decrease in theoretical maximum velocity (V_0) (-5.4 to -6.5 %)
2. Significant decrease in F-v slope (-10 to -11 %) was found, while a non-significant increase in theoretical maximum horizontal force (F_0) (4.9-5.2 %) occurred.
3. Significant increase in contact time (3.0-4.4%), and decrease in vertical stiffness (-6.2% to -12.0%), SF (3.4% to -3.6%). No change in step length or flight time.
4. No significant difference between anterior or posterior load positions.

Practical Applications:

1. No difference between anterior or posterior load positions in mechanical loading measures.
2. 3% BM WR allows individuals to reinforce ideal early acceleration with speed maintained during the initial acceleration phase (20 m).

3. Sprinting with 3% BM may benefit athletes requiring a more force dominant F-v profile by improving their external horizontal force production.

Acute Study: Forearm wearable resistance effects on sprint kinematics and kinetics

Macadam, Simperingham (13)

Purpose Statement:

To compare the effects of WR attached to the forearms on over ground sprint performance in semi-professional male athletes.

Introduction:

Twenty-two male amateur youth rugby players performed two 20 m over the ground sprints with and without 2% BM attached to forearms (Figure 14).

Figure 14: WR forearm loading of 2% BM

Key Findings:

1. No significant decrease in times to 10 m, but significant decreases between 10-20m (-2%).
2. A significant decrease was found in V_0 (-1.4%) and horizontal power output (-5.8%), while a non-significant decrease in theoretical maximum velocity (-4.2%) occurred.
3. A significant increase in contact time (6.5%) and step length (2.1%), and significant decrease in step frequency (-4.1%) and flight time (-5.3%) were found.

Practical Applications:

1. May reinforce ideal early acceleration with speed maintained during the early acceleration phase (10 m).
2. 2% BM forearm WR provides sufficient overload of arm action during sprinting without unduly affecting sprinting technique (<6% change).
3. Forearm WR may be suitable to enhance arm drive mechanics.
4. An increase in moment of inertia on the arms may alter the transfer of momentum to the body in the arm swing.

Acute Study: Effects of forearm wearable resistance on acceleration mechanics in collegiate track sprinters

Uthoff, Nagahara (14)

Purpose Statement:

How does forearm loading affect kinetic and kinematic characteristics during sprinting?

Introduction:

Arm action during sprinting has commonly been thought of as a coordinative mechanism to overcome rotation of the pelvis as a result of lower limb rotational movements, as well as a mechanism that functions to assist horizontal and vertical propulsion. Arm action contributes up to 22% of the body's total kinetic energy during block starts. Limited previous literature found that forearm wearable resistance loads >2%BM are required to significantly overload sprinting performance and associated step variables.

- Fourteen sub-elite male sprinters completed 30m sprints from block starts with and without 2%BM forearm loading (
- Analysed 4 phases of acceleration: start (steps 1-4), early acceleration (steps 5-8), mid-acceleration (steps 9-12), late acceleration (steps 13-16)
  - Kinetic Variables: performance, step frequency (SF), step length (SL), contact (CT) and flight (FT) time
  - Kinematic Variables: Mean propulsive force, Net horizontal impulse, propulsive impulse (HP_{H+}), braking impulse, vertical impulse (IMP_v)

Figure 15: 2% BM forearm loading distributed between both arms; loads evenly placed in a dove-tailed manner

Key Findings:

1. Sprint performance (times) were not significantly altered (p>0.05; -1.38% to -1.75%)
2. SL (+4.01%, ES=0.15 to 1.93) and HP_{H+} (+5.48%, ES=-0.30 to 1.88) significantly increased at the start of the sprint (phase 1)

3. Although SF (-4.86%, ES=-1.69 to -0.14) was lower, both FT (+7.70%, ES=0.02 to 1.56) and IMP_v (+4.12%, ES=0.07 to 1.72) were greater during late acceleration with loading

Practical Applications:

1. Forearm WR loading (2% BM) is a good method of overloading arm mechanics during sprinting due to negligible impacts on performance and technique
2. 2% BM forearm loading during the start phase of acceleration from a block may provide a method for overloading horizontal propulsion, by increasing SL without sacrificing SF
3. Practitioners should avoid using forearm loading during late acceleration, unless an athlete requires a stimulus which enables more vertical lift in order to reposition their limbs, potentially to minimize over-striding.

Acute Study: Force-velocity profile changes with forearm wearable resistance during standing start sprinting

Macadam, Mishra (15)

Purpose Statement:

How does forearm loading affect the horizontal force velocity profile of a collegiate male sprinter?

Introduction:

Arm mechanics function to maximize sprinting performance. A method of measuring sprint performance is achieved via measuring and athlete's power and acceleration ability, using a force-velocity profiles. Significant changes in the slope of the F-V profile, along with minimal sprint kinematic changes may elude towards wearable resistance being a training to improve horizontal force during early acceleration of sprinting.

- Fourteen sub-elite male sprinters completed 30m sprints from split-stance starts with and without 2%BM forearm loading (Figure 15)
- Analysed force velocity profiles including theoretical horizontal velocity (V_0), theoretical horizontal force (F_0), horizontal power (P_{MAX}), and the slope of the F-V curve (S_{FV})

Key Findings:

1. Sprint performance (times) were significantly increased at -10m (+2.7%, ES: 0.54), -20m (+2.1%, ES: 0.57), and -30m (+1.9%, ES: 0.60)
2. Significantly decreased P_{MAX} was found when loaded (-6.1%, ES: 0.66)

Practical Applications:

1. Sprinting from a split-stance start with forearm WR may be a method to train sprinting performance over the mid- to late- acceleration phases
2. Sprinting with forearm WR affects the force component of the F-V profile, thus altering power capability of trained sprinters
3. Forearm WR may be a potential training method for athletes aiming to enhance force/power adaptations during acceleration, from a standing start
4. Forearm WR during sprinting may affect different athletes different, thus a good understanding of the specific horizontal F-V requirements of the sport/athlete is important prior to utilizing forearm WR.

Acute Study: The effect of lower limb wearable resistance location on sprint running step kinematics

Feser, Macadam (16)

Purpose Statement:

How do different WR placement of the leg effect 50 m sprint performance

Introduction:

Fourteen track and field athletes performed two 50 m over the ground sprints with and without 2% BM attached to either the thigh or shank (Figure 16). WR was placed and oriented to the most distal position from joint of rotation.

Figure 16: Thigh and shank WR of 2% BM

Key Findings:

1. Both the thigh and shank WR significantly decreased the maximal velocity achieved (-1.8 to 2%), though 10 m and 50 m sprint times were minimally changed ($p > 0.05$).
2. During the acceleration phase, the only significant difference to the unloaded condition was step frequency with shank WR (-2.1%).
3. During the maximal velocity phase, shank WR significantly changed step frequency (-2.5%), contact time (2.1%), and flight times (3.3%); thigh WR significantly changed step frequency (-1.4%) and contact time (2.9%).

Practical Applications:

1. As slightly greater changes to step kinematics were found throughout both phases of the sprint distance with shank WR, practitioners may wish to utilize this placement for athletes needing to overload the acceleration and maximal velocity phases.

2. It appears peripheral loading (2% BM) of the thigh and shank can be used to overload step frequency and contact time but not step length and width.

Acute Study: Acute spatiotemporal and muscle excitation responses to wearable lower limb loading during maximal velocity sprinting

Hurst, Kilduff (17)

Purpose Statement:

To quantify the mechanical effects of adding WR to the thigh or shank segments during maximal velocity sprinting.

Introduction:

Eight university level sprinters performed two 40 m sprints under each condition (unloaded, thigh WR of 1.7% BM, shank WR of 0.6% BM).

Key Findings:

1. There was a possibly small decrease in maximum velocity In both thigh (-1.8%) and shank (-1.4%) conditions, which was associated with a likely small decrease in step frequency (thigh -3.7%, shank -2.3%) and no clear difference in step length (1-1.5%).
2. There was a likely small increase in contact time with thigh WR (2.5%), and possibly small increases in both flight time (2.8%) and contact time (1.2%) with shank WR.
3. There were no clear differences in peak muscle excitation (EMG assessment) of the biceps femoris or semitendinosus between conditions.

Practical Applications:

1. As changes in sprint performance were small, WR may provide a suitable high degree of specificity training method to bridge the gap between phases of a periodised training plan.
2. As there were no clear differences in biceps femoris or semitendinosus EMG muscle activity between the conditions, WR of this magnitude does not increase the excitation demand placed on the hamstrings.

Acute Study: Effects of forearm wearable resistance during accelerated sprints: From a standing start position

Uthoff, Macadam (18)

Purpose Statement:

To determine the acute changes in step kinematic and kinetic characteristics when wearable resistance equivalent to 2% BM was attached to the forearms during short (30-m) over-ground accelerated sprinting tasks.

Introduction:

14 recreational track and field male athletes performed 30 m maximal effort accelerated sprints from a 2-point standing start with and without 2% body mass forearm wearable resistance (Figure 19), across in-ground force plates. Step kinematic and kinetic variables were determined over four acceleration phases, comprising the start (steps 1-4), early acceleration (steps 5-8), mid-acceleration (steps 9-12) and late acceleration (steps 13-16). The following variables were analysed:

- Step duration: foot strike of one leg to foot strike of the opposite leg
- Contact time: duration of foot contact with the ground
- Flight time: duration of no foot contact with the ground
- Step length: distance between ground contact foot placements for two adjacent steps (L and R) in the A-P direction
- Step Frequency: Inverse of step duration (1/step duration = 1/s)
- Step Velocity: step length x step frequency
- Impulse: Vertical, mediolateral, propulsive, braking and net horizontal

Figure 17: Forearm wearable resistance load distribution.

Key Findings:

1. Sprint performance did not differ between unloaded and loaded WR at 10-m (-1.41%; ES = -0.32), or 30-m (-0.76%; ES= -0.24)
2. Sprinting with forearm WR significantly decreased step frequency during phase two ($p < 0.05$, -3.42%; ES = -0.81) and three (-3.60%; ES = -0.86), and step velocity during phase four ($p < 0.05$, -3.61%; ES = 0.91).
3. Wearing forearm WR of 2% body mass does not severely impede overall sprinting performance as derived by time to completion.

Practical Applications:

4. The findings suggest that 2% body mass overload can be applied to the upper limbs with limited detriments to sprinting technique and performance.
5. Identifying specific training strategies which improve step-related characteristic and arm action during sprinting may assist practitioners in programming for improved sprint performances and training adaptations.
6. The cumulative effect of the changes in force application resulting in the expression of longer contact times, flight times and step length, with a reduction in step frequency, provides practitioners with a sound basis for implementing forearm WR as part of their training strategy to overload and enhance accelerated sprinting performance.

Acute Study: Kinetic and kinematic effects of asymmetrical loading of the lower limb during high-speed running

Acker, Eberle (19)

Purpose Statement:

The aim of this study was to compare the kinetics and kinematics of high-speed running with unilateral lower body wearable resistance.

Introduction:

Light lower-limb WR has little effect on running biomechanics, however, asymmetrical wearable resistance may potentially alter the kinetics and kinematics of high speed, enabling greater loading or unloading of an injured or rehabilitative lower limb. 12 (7 males and 5 females) participated in a cross-sectional study design, to quantify the influence of asymmetric calf loading on the kinematics and kinetics during 90% maximum sprinting velocity. In a random order, participants ran with zero (L0) wearable resistance and with loads of 300 g (L300). And 600 g (L600) fixed to one shank (Figure 20). A non-motorized treadmill quantified vertical and horizontal kinetics and step kinematics (Figure 21). The kinetics and kinematics of the loaded (L0, L300 and L600) and unloaded (UL; UL0, UL300, and UL600) limbs were compared.

Figure 18: Wearable resistance load placement.

Figure 19: Non-motorized treadmill setup.

Key Findings:

1. Vertical ground reaction force of the loaded limb tended to increase between unloaded and 300 and 600 conditions (effect size [ES] = 0.48 to 0.76, all $P \leq .12$).
2. Horizontal step force of the UL tended to decrease (ES = 0.54 to 1.32, all $P \leq .09$) with greater external loading.
3. Step length increased in the UL in 0 versus 300 and 600 conditions (ES = 0.60 to 0.70, all $P \leq .06$).
4. Step frequency decreased in the ULs in unloaded versus 300 and 600 conditionings (ES = 0.73 to 1.10, all $P \leq .03$).

5. Mean step velocity tended to be greater in the ULs than the 300 and 600 conditions (ES = 0.52 to 1.01, all $P \leq .10$).
6. Only 4 of 16 variables were significantly different between the 300 and 600 conditions.

Practical Applications:

7. Asymmetrical shank resistance could be used during high-speed running to reduce or increase the kinetic loading of injured/rehabilitative limb during return to play protocols.
8. Asymmetrical wearable resistance could also be used to alter step kinematics in runners with known asymmetries
9. Meaningful alterations in high-speed running biomechanics can be achieved with only 300 g of shank loading.

Acute Study: Changes to horizontal force-velocity and impulse measures during running acceleration with thigh and shank wearable resistance

Feser, Bezodis (20)

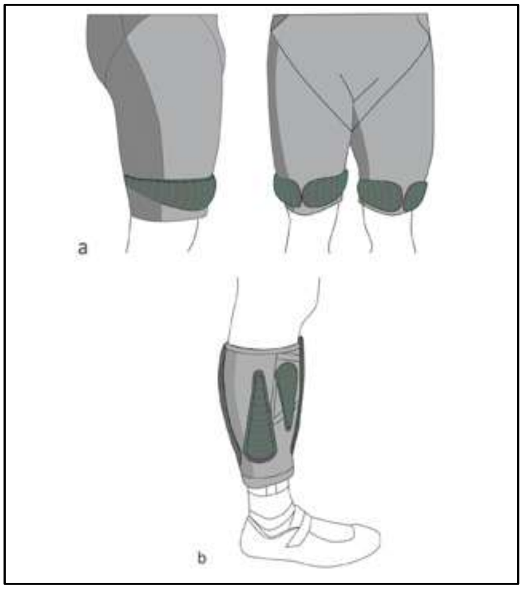
Purpose Statement:

The purpose of this study was to determine the effect of two different wearable resistance placements (i.e., thigh versus shank) on horizontal F-V and impulse measures during sprint running acceleration.

Introduction:

This study determined the effects of two wearable resistance (WR) placements (i.e., thigh and shank) on horizontal force-velocity and impulse measures during sprint running acceleration. Eleven male athletes performed 50 m sprints either unloaded or with WR of 2% body mass attached to the thigh or shank. Inground force platforms were used to measure ground reaction forces and determine dependent variables of interest.

Figure 20: Example wearable resistance load placements for (a) the thigh wearable resistance experimental condition and (b) the shank wearable resistance experimental condition.



Key Findings:

1. Increases in sprint times and reduction in maximum velocity were trivial to small when using thigh WR (0.00-1.93%).
2. Increases in sprint times and reduction in maximum velocity were small to moderate with shank WR. (1.56-3.33%).

3. Athletes maintained or significantly increased horizontal force-velocity mechanical variables with WR (ES = 0.32 - 1.23), except for theoretical maximal velocity with thigh WR, and peak power, theoretical maximal velocity and maximal ration of force with shank WR.
4. Greater increases to braking and vertical impulses were observed with shank WR (2.72 - 26.3% compared to unloaded) than with thigh WR.

Practical Applications:

5. These findings highlight the velocity-specific nature of this resistance training method and provide insight into what mechanical components are overloaded by lower-limb WR.

Training Study: Thigh positioned wearable resistance improves 40m sprint performance: A longitudinal single case design study

Macadam, Nuell (21)

Purpose Statement:

To quantify the mechanical changes that occur following a five-week sprint training program with WR attached to the thighs.

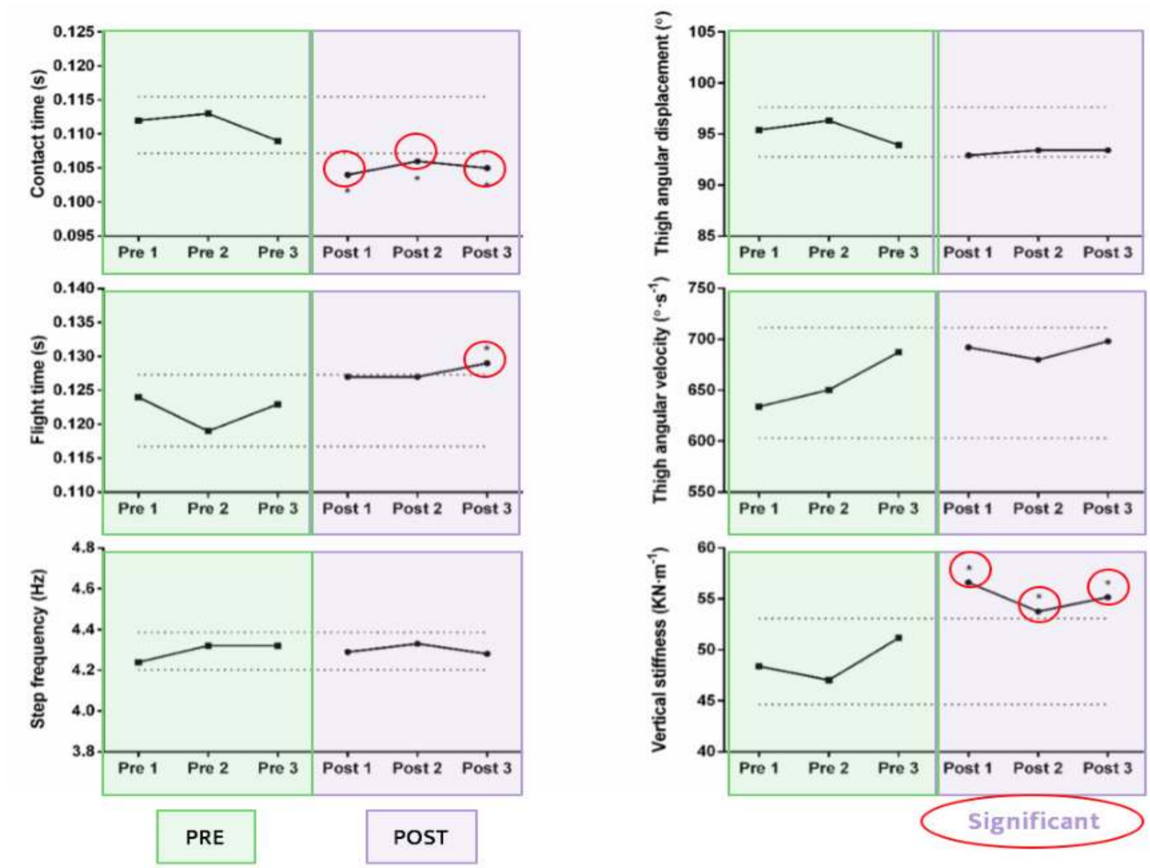
Introduction:

One male former sprinter (32 years, 72.4 kg and 180.2 cm, 10.90 s 100 m time) undertook a five-week intervention with WR of 2% BM attached to the thighs. The athlete completed two to three sprint session per week in a periodised manner with WR.

Key Findings:

1. Substantially faster times were found at all distances of 10 m (-3.4%), 20 m (-2.5%), 30 m (-2.4%), and 40 m (-2.4%).
2. Theoretical maximum velocity (1.2%), theoretical measures of horizontal force (7.1%) and maximum power (8.4%) were all substantially increased. Contact times were substantially decreased (-5.5%), while flight times (4.7%) and vertical stiffness (12.9%) were substantially increased

Figure 21: Changes in sprint kinematics



Practical Applications:

1. WR provides a sprint-specific method for rotational overload and subsequent speed specific adaptation with decreases in sprint times being accompanied by increases of sprint mechanical properties, reductions in contact times and increases in vertical stiffness
2. WR attached to the thigh enables loads to be applied directly to the body that will stress specific sprint movements under the specific demands of an actual sport and competitive environment, without compromising the speed of motion, range of motion and specific skill.

Training Study: Thigh positioned wearable resistance affects step frequency, not step length during 50m sprint-running

Macadam, Nuell (22)

Purpose Statement:

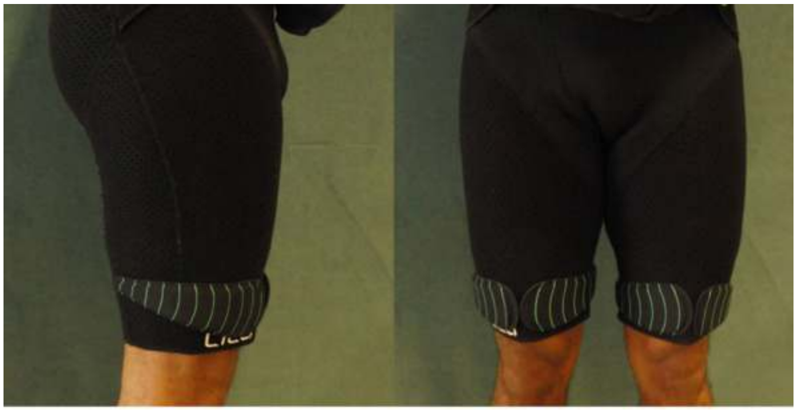
To determine the acute changes in spatio-temporal, impulse, and vertical stiffness variables when 2% BM was attached distally to the thighs during maximal effort sprinting.

Introduction:

15 Japanese sprinters performed 2 maximal effort, 50m sprints from block starts under 2 different loading conditions (2%BM and unloaded). Sprint times were measured using timing gates at 10m and 50m. Spatio-temporal, impulse, and vertical stiffness variables were determined from 54 in-ground force platforms (1000Hz) [-1.5m to 50.5m].

- Step duration: foot strike of one leg to foot strike of the opposite leg
- Contact time: duration of foot contact with the ground
- Flight time: duration of no foot contact with the ground
- Step length: distance between ground contact foot placements for two adjacent steps (L and R) in the A-P direction
- Step Frequency: Inverse of step duration (1/step duration = 1/s)
- Step Velocity: step length x step frequency
- Impulse:
- Vertical Stiffness:

Figure 22: Wearable Resistance of 2% Body Mass Attached to the Distal Aspect of the Thighs



Key Findings:

1. Thigh WR has a greater effect on step frequency (decreased) than step length, leading to longer contact times.
2. Thigh WR resulted in 4.8% decrease in net anterior-posterior impulses in steps 5-14 due to an earlier foot-strike, and thus greater braking impulse.

3. Vertical stiffness was decreased 5.5% between steps 5-14, potentially due to increased flexion at the knee and ankle joints during the support phase (increased contact times.

Practical Applications:

1. WR provides a sprint-specific method for rotational overload and subsequent speed specific adaptation with decreases in sprint times being accompanied by increases of sprint mechanical properties, reductions in contact times and increases in vertical stiffness
2. WR may be a training tool to overload net anterior-posterior impulses, resulting in positive adaptations to horizontal force production, to overcome the additional loading. (Teach the sprinter to increase horizontal force production, and decrease braking of each step)
3. Thigh WR may provide a training stimulus to overload vertical stiffness, effectively overloading the stretch-shortening cycle, to help reduce leg compliance.

Swimming

Thesis: Wearable resistance technology to enhance swimming performance (study 1)

Quirke (23)

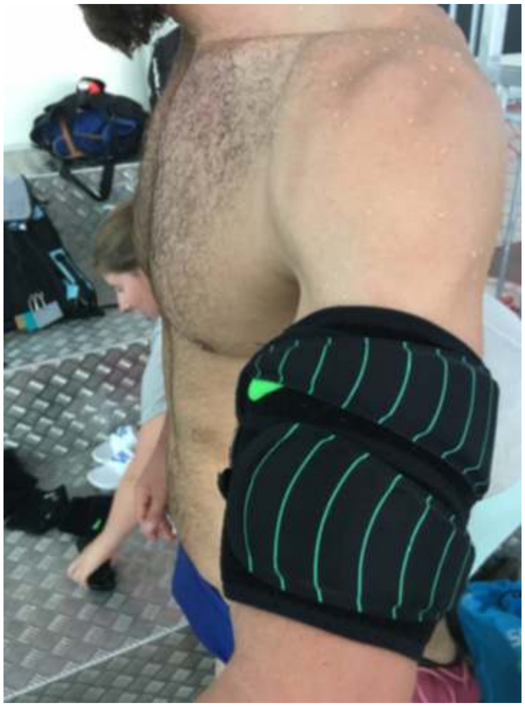
Purpose Statement:

The aims were to determine the acute metabolic effects of variable proximal upper limb loading using WRT during submaximal swimming

Introduction:

The principle of training specificity indicates that added resistance training in swimming will be more effective if applied through the exact stroke mechanism in an aquatic environment. Fifteen (male=7; female=8) national level swimmers completed two sessions, with 24 hrs recovery in between. The first session involved determination of the subjects' lactate threshold using a 7x200m incremental step test. The second session required each subject to complete 6x200m freestyle swims at individualized submaximal speeds with variable loads ranging from 0g-500g proximally loaded to each arm using WRT. During each swim the subjects were randomly assigned one of six WR loads [0g (control), 100g, 200g, 300g, 400g, 500g] to be proximally loaded to each upper arm compression sleeve (Figure 23). RPE was also collected after each 200m to see if the subjects identified a difference in difficulty between the different WR loads

Figure 23: Proximal Upper Arm Loading of Wearable Resistance



Key Findings:

1. There was no substantial difference in swim times for males between any WR loaded trials
2. There was no increase in RPE in males (mean: 15.4 ± 2.1 RPE)
3. Males experienced substantially higher BL levels when loads exceeded 300g; females BL levels were unclear
    a. 400g: ↑0.74 ± 1.32 mmol-1, 0.41, (-0.13 - 0.96)
    b. 500g: ↑2.40 ± 3.06mmol-1, 1.29, (-0.06-2.63)
4. There were significantly slower swim speeds with loads over 300g for females
    a. 400g (↑3.11 ± 2.56sec, 1.9%, (0.8-3.1))
    b. 500g (↑4.05 ± 2.35sec, 2.6%, (1.4-3.8))
5. There was a significantly small increase in female RPE over 200g loading trials compared to the control (0g)
    a. 300g (↑1.2 ± 1.9RPE, 0.53, (-0.19 - 1.25))
    b. 400g (↑1.1 ± 1.9RPE, 0.58, (-0.11 - 1.27))
    c. 500g trial (↑1.1 ± 2.3RPE, 0.58, (-0.26 - 1.42))

Practical Applications:

1. Males and females respond differently to added WR upper arm loads during submaximal swimming
2. Wearable resistance during swimming may be used to influence the “training zone” of the male athlete, likely by changing the input of each energy system and applying overload to the upper body musculature
3. Females may not be strong enough to withstand higher loads during swimming and maintain swimming speeds
4. Upper arm WR loads exceeding 300g may be too high for female swimming athletes
5. For swimming, gender specific loading and training manipulation is necessary

Agility

Editorial: Wearable resistance training for speed and agility

Cleary Dolcetti, Cronin (24)

Purpose Statement:

How can wearable resistance be a powerful training modality to improve speed and agility, and how it can be used to first coach and then train athletes.

Introduction:

Most resistance training exercises are vertically orientated, rather than horizontally or laterally which are principle components of speed and agility. Furthermore, traditional resistance training exercise tend to be slower, less range of motion, and acyclic, where movement is typically cyclic in nature. The importance of the principle of specificity in optimizing transference of training adaptation is important for all athletes, more increasingly so for the elite. WR training involves an external load being applied to segments of the body during movement and is an example of one concept of training specificity. WR has the potential to address limiters to transference such as:

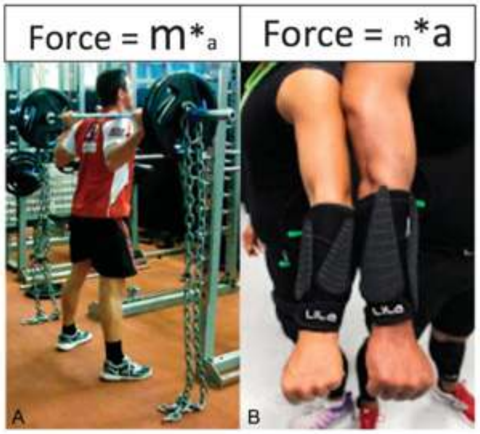
- Lack of velocity
- Lack of range of motion
- Contraction type
- Metabolic specificity to the activity of interest

Argument for Wearable Resistance:

Mechanical

- WR allows for other ways of developing high forces, through light loads (grams, kilograms) (Figure 24)
- WR provides a direct rotational overload to the limb of interest and the associated proximal joints and musculature
- A change in rotational inertia increases the kinetic output of the joint proximal to the location of the added load, with a greater effect when the load is more distal and when the magnitude is increased.

Figure 24: Different methods for the development of force capability



Neural

- Improving neural efficiency to enhance force capability and movement quality is key for many S&C coaches
- Adding load to a sports movement would be a suitable strategy for achieving the specificity needed to develop the necessary intramuscular coordination

Metabolic

- WR provides a metabolic stimulus during sprinting and agility performance, particularly if the activities are repetitive in nature and more reflective of actual competition-specific demands and durations

Tips for Wearable Resistance Use

The use of WR in a periodised plan depends on the requirements of the sport and the individual needs of the athlete. The value of WR as a training tool is during specific strength training; when looking to modify the use of traditional resistance training to find more relevant ways to overload the body that re force, speed, and ROM relevant to the sport

Individualisation - *If the load feels wrong, change it*

- Loads must be first "felt" and then "lifted" (i.e. if the loading is too heavy, unnatural, or uncomfortably orientation, it should be adjusted)
- Load adjustments should be both user and coach driven

Specificity - *Reduce the load not the speed*

Progressive Overload - *Progress in grams, not kilograms*

- There is an inherent trade-off between load and specificity
- The load is secondary to the movement
- Progression can be achieved by moving the same load more distally from the axis of rotation; thus increasing the rotational inertia

Overtraining - *Listen to your body*

- Although light, WR is still resistance; high velocity movements are generally MORE fatiguing

Weightlifting

Acute Study: The effect of wearable resistance on power cleans in recreationally trained males

Marriner, Cronin (25)

Purpose Statement:
To compare the effects of different WR magnitudes on power clean performance in resistance trained males.

Introduction:
WR of 5% or 12% BM attached to the posterior of the upper and lower body (Figure 25) was used to examine the acute effects on power clean lifting. Nine recreational trained males performed two reps of the power clean (PC) at 50 and 70% 1RM with each WR condition, i.e. power cleans with and without load redistributed from the bar to the body via WR, in a randomized order.

Figure 25: Posteriorly loaded upper and lower body WR of 5% and 12% BM

Key Findings:
1. WR significantly increased acute power output (11.5-16.8%) via increased barbell velocity (3.3-4.7%).
2. Similar GRF between WR and traditional power clean loading were observed.
3. Positive acute technique changes for power clean performance with WR (barbell rearward displacement increased by 17.8%).
4. Greater beneficial changes found with 12% than 5% BM redistribution.

Practical Applications:
1. Provides a means to acutely increase power clean barbell velocity and power output.
2. Due to reduced barbell load, enables training for less technically proficient lifters or lifters returning from injury, while minimising injury risk (e.g. wrist mobility limitations).
3. Enables lifters to focus on technical aspects of the lift (minimising the horizontal displacement of the barbell).
4. May be suitable for athletes who perform high velocity movements.

Training Study: Redistributing load using wearable resistance during power clean training improves athletic performance

Marriner, Cronin (5)

Purpose Statement:

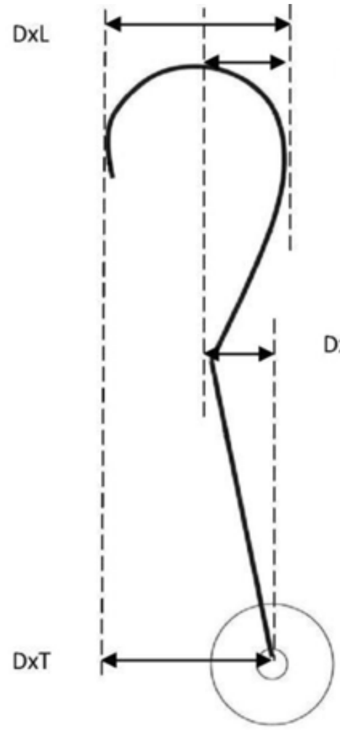
To investigate how power clean training with WR over a 5-week period effects power clean maximum strength performance in resistance trained males.

Introduction:

WR of 12% attached to the posterior of the upper and lower body (Figure 2) was used during a 5-week training study into the effects on power clean lifting. Two groups of eight recreational trained males completed power cleans either with load redistributed from the bar to the body via WR, or via traditional power clean training. Both groups performed two sessions a week in an undulating periodised plan. Technique variables during power clean bar path are shown in Figure 26.

Figure 26: Technique variables during power clean bar path.

(DxL = furthest forward position to catch, DxT = start position to catch, Dx2 = start position to beginning of 2nd pull, DxV = 2nd pull position to forward position CxH = barbell catch height)



Key Findings:

1. Significant increase (4.2%) in 1RM power clean in WR group compared to traditional loading.
2. Barbell velocity increased at 70 and 90% 1RM (ES= 0.16 to 0.74) in the WR group.
3. Power output increased at 50, 70 and 90% 1RM (ES = 0.33 to 0.62) in the WR group.

4. Similar GRF between WR and traditional loading.
5. Positive technique changes for power clean performance with WR at 70 and 90% 1RM (ES = 0.23 to 0.96).

Practical Applications:

1. Provides a means to chronically increase power clean barbell velocity and power output.
2. Method to increase 1RM power clean.
3. Due to reduced barbell load, enables training for less technically proficient lifters or lifters returning from injury, while minimising injury risk (e.g. wrist mobility limitations).
4. Enables lifters to focus on technical aspects of the lift (minimising the horizontal displacement of the barbell).

Golf

Acute Study: Wearable resistance acutely enhances shot distance and club head speed in female skilled golfers

Macadam, Chau (26)

Purpose Statement:

To investigate the effects of WR on golf swing performance in highly skilled female golfers.

Introduction:

WR of ~3% BM was attached laterally to the posterior of the upper and lower body (Figure 27) on five highly skilled female golfers. Each subject performed 10 shots unloaded and 10 shots with WR in a randomised order.

Figure 27: Lateral and posteriorly loaded upper and lower body WR of ~3% BM

Key Findings:

1. Significant acute increases were found in shot distance (7%) and club head speed (3.5%)

2. Relative vertical GRF (11.4%, lead side), and relative mediolateral GRF (7.1%, trail side) were significantly increased with WR as compared to the unloaded condition.

Practical Applications:

1. A golf swing specific method to acutely improve golf shot distance, club head speed and GRF.
2. May be a training tool to increase rotational force and velocity without unduly affecting swing mechanics without the loads attached to the arms.

Acute Study: Effects of weighted arm sleeve loading on golf shot parameters

Uthoff, Lynn (27)

Purpose Statement:

To examine how unilateral and bilateral loading between 100-400 g placed on the forearms, affected golf shot parameters related to carry distance (i.e., the distance a ball travels in the air) and accuracy and determine if any potentiation, or unloading affect was observed once the wearable resistance was removed.

Introduction:

Nine experience right-handed golfers (eight males and one female) with an average handicap of 3.8 ± 2.6 performed golf shots with and without wearable resistance (WR) on their forearms (Figure 24). A single session, acute randomised cross-sectional design was used to examine the effects of different arm loading patterns on drive shot parameters. Subjects warmed up as per their usual procedures. They then performed five unloaded swings of their own 7 iron club. Thereafter, five swings were performed under seven randomised loading conditions (4 loads and 3 positions). Finally, five unloaded swings were performed after the loading conditions.

Figure 28: Loading placement for forearm WR with bilateral 200g

Key Findings:

1. Unilateral loading on the lead arm resulted in increased carry distances from 1.68-1.78%, with 200 g loading significantly enhancing performance ($p = 0.04$; ES = 0.72).
2. Unilateral loading of both 200 g and 400 g on the lead arm resulted in a large and very large change to carry side distance leading to a leftward ball trajectory ($p = 0.02$ and 0.01, respectively; ES = -2.07 and -4.43, respectively).

Practical Applications:

3. arm-loaded WR may be used to influence swing mechanics, which may assist ball carry trajectory in the desired direction, depending on a golfer's individual abilities and needs.

Combat Sports

Pilot Study: The effects of a six-week EXOGEN® training program on punching and kicking impact in amateur male combat athletes: A pilot study

Vecchio, Stanton (28)

Purpose Statement:

Examine effect of 6-week EXOGEN® combat program on punching and kicking impact power in amateur male combat athletes.

Introduction:

Seventeen amateur (minimum 2 years of MMA or kickboxing) combat athletes were allocated to either an EXOGEN® (n=10, 28.2 ± 1.7 years, 79.5 ± 7.7kg, 176.6 ± 4.7 cm) or Control (n=7, 29.0 ± 2.0 years, 79.8 ± 11.9kg, 177.7 ± 5.7 cm) group for six weeks. A pre-post study design was used with the following performance tests: Standing vertical jump test, 5RM half-squat, and 5RM bench press. Impact power testing was assessed in the following movements: Lead-hand jab, read-hand cross, rear-leg front kick, and Rear-leg roundhouse kick (using StrikeMate®).

The six-week periodised program consisted of 3 x 60-minute training sessions/week. The EXOGEN® group performed 2 out of 3 sessions with wearable resistance (Table 4). The suit consisted of Lila® EXOGEN® compression-based arm sleeves, pants, and calf sleeves, and loads (2-4.5% BW) located over the midline of the intended appendage. Loads were positioned over the upper and lower lib, lateral hip, anterior thigh, anterior and posterior lower limb (Figure 29).

Figure 29: EXOGEN® Load Placement

Table 4: Six Week EXOGEN Loading Scheme

Week	EXOGEN® Garment	Location	Weight Load Selection	Bilateral Limb Load	Total Body Load
1	Shorts	Anterior Thigh	200g x 2	600g	1.8 kg
		Lateral Hip	100g x 2		
	Arm Web	Upper Arm	100g x 2	600g	
		Forearm	100g x 1		
	Calf Sleeves	Posterior Lower Limb	200gx2	600g	
		Anterior Lower Limb	100gx2		
2	Shorts	Anterior Thigh	200gx4	1000g	2.6kg
		Lateral Hip	100gx2		
	Arm Web	Upper Arm	200gx6	1000g	
		Forearm	100gx4		
	Calf Sleeves	Posterior Lower Limb	200gx1	600g	
		Anterior Lower Limb	100gx1		
2	Shorts	Anterior Thigh	200gx2	600g	1.8kg
		Lateral Hip	100gx2		
	Arm Web	Upper Arm	100gx2	600g	
		Forearm	100gx1		
	Calf Sleeves	Posterior Lower Limb	200gx2	600g	
		Anterior Lower Limb	100gx2		
3	Shorts	Anterior Thigh	200gx4	1000g	2.6kg
		Lateral Hip	100gx2		
	Arm Web	Upper Arm	200gx4	1000g	
		Forearm	100gx4		
	Calf Sleeves	Posterior Lower Limb	200gx1	600g	
		Anterior Lower Limb	100gx1		
4	Shorts	Anterior Thigh	4 x 200g	1200g	3.2kg
		Lateral Hip	4 x 100g		
	Arm Web	Upper Arm	4 x 200g	1000g	
		Forearm	2 x 100g		
	Calf Sleeves	Posterior Lower Limb	4 x 200g	1000g	
		Anterior Lower Limb	2 x 100g		
5	Shorts	Anterior Thigh	4 x 200g	1400g	3.6kg
		Lateral Hip	6 x 100g		
	Arm Web	Upper Arm	4 x 200g	1200g	
		Forearm	4 x 100g		
	Calf Sleeves	Posterior Lower Limb	4 x 200g	1000g	
		Anterior Lower Limb	2 x 100g		

Key Findings:

1. A six week EXOGEN® training programme significantly improved jab impact power ($p=0.025$, ES=0.73, +25.9% change)
2. A six week EXOGEN® training programme significantly improved rear-hand cross impact power ($p=0.004$, ES=1.00, +51.2% change)
3. A significant increase in bench press strength ($p=0.008$, ES=0.32, +6.0% change) was observed in the EXOGEN® trained group
4. A significant increase in vertical jump height ($p=0.025$, ES=1.50, +19.2% change) and 5RM half-squat ($p=0.02$, ES=0.26, +6.9% change) was observed in the EXOGEN® trained group
5. Front kicking impact power did not significantly increase in either the EXOGEN® or control group

Practical Applications:

1. A six week periodised EXOGEN® training programme significantly improves both jab and rear-cross punching impact power in amateur male combat athletes, which may improve an athlete's change of success in striking martial arts.
2. Greater loads may need to be used to improve front kick impact power
3. EXOGEN® training may be beneficial for vertical jump height, half squat, and bench press strength, particularly when combined with plyometric exercise

Team Sports

Training Study: Effects of warming up with lower-body wearable resistance on physical performance measures in soccer players over an 8-week training cycle

Bustos, Metral (29)

Purpose Statement:

The aim of this study was to quantify the physical performance effects of adding lower-limb wearable resistance to a youth soccer warm-up over 8-weeks

Introduction:

Soccer players spend a considerable amount of time training on-field as well as playing games, forcing strength and conditioning professionals to use time efficient resistance training methods to promote optimal adaptations in congested schedules. Resistance training as a part of what athlete do on the field may provide a specific physiological adaptation to optimize transference directly to their sport, without adverse effects on technique. Further, warm-up programs are designed to prepare the body for specific movements encountered during the sport, and thus performing a warm-up consisting of specific movements with WR affixed to the legs may optimize transfer between training and actual sports movements with minimal effects on technique.

Thirty-one national level U20 Argentinian soccer players (15-18 years, 68.5 ± 5.42kg, 176 ± 0.61cm) were matched for sprinting ability and split into two groups; control group (CON) (n=16) and WR group (n = 15). All participants were tested pre-, mid-, and post- the 8-week training protocol. After a 15-minute standardized warm-up, participants were taken through a testing battery.

Table 5: Performance tests conducted pre-, mid-, and post- 8 week intervention

Speed	Repeated Sprint Ability	Jump
0 - 10 meters	(RSA): 6 x 40 meters *20 meters → change direction 180° → 20 meters*	Bilateral vertical countermovement jump (CMJ)
0 - 20 meters		Single leg horizontal jump (SLJ)

All subjects performed an 8-week program; WRT group with periodised weight (Table 6). At training sessions, all subjects performed a warm-up protocol consisting of active stretching, technical drills with the ball, and high-intensity accelerations, decelerations, changes of direction, and plyometric and sprint exercises. The WRT group wore compression garments with 200g-600g distributed on each calf (Figure 30) during the warm-up 2-3 times per week.

Table 6: Periodized 8-week loading scheme for the wearable resistance training (WRT) group

Weeks	Load-Placement	Session 1	Session 2	Session 3
1	200g, posterior, proximal	200g	200g	200g
2	200g, posterior, distal	200g	200g	200g
3	400g, posterior, proximal	400g	400g	400g
4	600g, 400g posterior, proximal	400g	Testing	400g
5	400g, posterior, proximal	400g	400g	400g
6	600g, 400g posterior, proximal	600g	600g	600g
7	600g, 400g posterior, distal	600g	600g	600g
8	600g, 400g posterior, proximal	600g	600g	600g

Figure 30: Illustration of load placement

Key Findings:

1. The WRT group was found to be more effective (P< 0.05) in reducing 10- and 20-m sprint times for the entire pre-post training cycle than the unloaded CON (ES: -1.06 to -0.96) (60.0% - 66.7% vs. 18.8% - 37.5% > SWC)
2. No differences between groups for RSA either within groups or between groups for any training block comparison

3. Both WRT and CON groups improved SLJ performance after the 8-week block (ES = 0.85 and 0.93) (86.7% - 62.5% > SWC), yet no difference in magnitude change were identified over any training blocks

Practical Applications:

1. Wearable resistance can be used to improve 10m and 20m sprint performance as a part of a warm-up rather than a dedicated sprinting session
2. Calf loaded WR protocol above provides a movement-specific training stimulus that positively influences sprint ability
3. In terms of anaerobic adaptations, the accumulated load over 8 weeks of warming up with WR limb loads may be insufficient with resistance less than 600g
4. WR, when worn during a horizontal ground-based warm-up over 8 weeks, enhances an athletes ability to apply force horizontally, but does not improve vertical jump performance (CMJ)

Training Study: Does warming up with wearable resistance influence internal and external training load in national level soccer players?

Uthoff, Bustos (30)

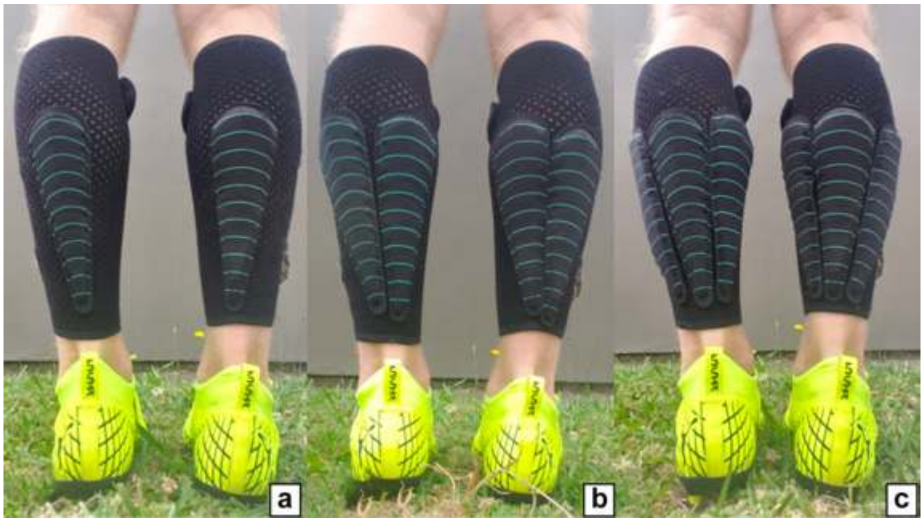
Purpose Statement:

The aim of this study was to investigate whether wearing wearable resistance during a warm-up affects GPS or sRPE measures and whether any delayed effects would be present in the subsequent training session when wearable resistance was removed.

Introduction:

Adding WR to training results in superior performance compared with unloaded conditions. However, it is unclear if adding WR during a warm-up influences training load (TL) in the subsequent session. This research tracked TL in 28 male soccer players which were allocated to either a WR training (WRT = 14) or unloaded (CON = 14) group. Both groups performed the same warm-up and on-field training for 8 weeks, with the WRT group wearing 200 g to 600 g loads on their lower leg (Figure 28) during the warm-up. External TL was measured vid global positioning system data and internal TL was assessed using session rating of perceived exertion (sRPE x time per session).

Figure 31: Example of calf loading patterns for (a) 200 g, (b) 400 g and (c) 600 g.



Key Findings:

1. No statistically significant between-group differences ($p \geq 0.05$) were identified for any TL measurement during either warm-ups or training sessions.
2. Lower leg WR resulted in trivial to moderate effects for all external TL metrics (-16.9% to 2.40: d = -0.61 to 0.14) and sRPE (-0.33%; d = -0.03) during the warm-up.
3. Lower leg WR resulted in trivial to small effects on all external TL metrics (−8.95% to −0.36%; d = −0.45 to −0.30) and sRPE (3.39%; d = 0.33) during training sessions.

Practical Applications:

4. Warming up with lower leg WR negatively affects neither the quality and quantity of the warm-up nor the subsequent training session once WR is removed.
5. Based on these results, using WR on the lower leg during on-field warm-ups may be a means to "microdose" strength training while not unduly increasing TL.

Training Study: The effects of lower-limb wearable resistance on sprint performance in high school American football athletes: A nine-week training study

Feser, Korfist (31)

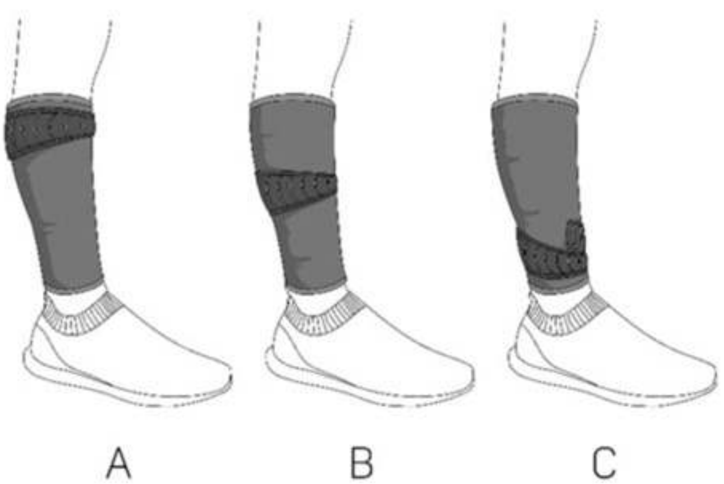
Purpose Statement:

The purpose of this study was to determine the effects of a lower limb WR sprint running training intervention on athlete speed capabilities following a nine-week off-season, low volume training period for American football high school athletes.

Introduction:

Time constraints often result in the challenge to fit desired programming into training time allotments. Wearable resistance may be an option to optimise the training content in function of constrained training time. Nineteen athletes completed pre- and post-intervention testing of two maximal effort 30m sprints. Horizontal force-velocity mechanical profiling variables, sprint times, and maximal velocity were calculated from sprint running velocity data collected by a radar device. Each athlete completed seventeen dedicated sprint training sessions during the off-season. The intervention (WR) group completed the sessions with 1% body mass load attached to the shanks (i.e., 0.50% body mass load on each limb). The load placement progressed through the training block from a proximal shank location to mid-shank and finished at a distal shank location to provide a progressive overload (Figure 32). The control group completed the same training sessions unloaded.

Figure 32: Wearable resistance placements. A: proximal, B: mid, C: distal.



Key Findings:

1. Post-intervention, no statistically significant between group differences were observed ($p>0.05$).
2. Athletes in both groups experienced increases in velocity measures following the sprint training.
3. The greater adjusted mean theoretical maximal velocity scores ($p>0.05$; ES = 0.30) found for the WR group compared to the control group at post-intervention may suggest that WR amplifies the nuances of the training protocol itself.

Practical Applications:

4. Coaches can consider using lower-limb WR training to increase in-session workloads during periods of low volume training

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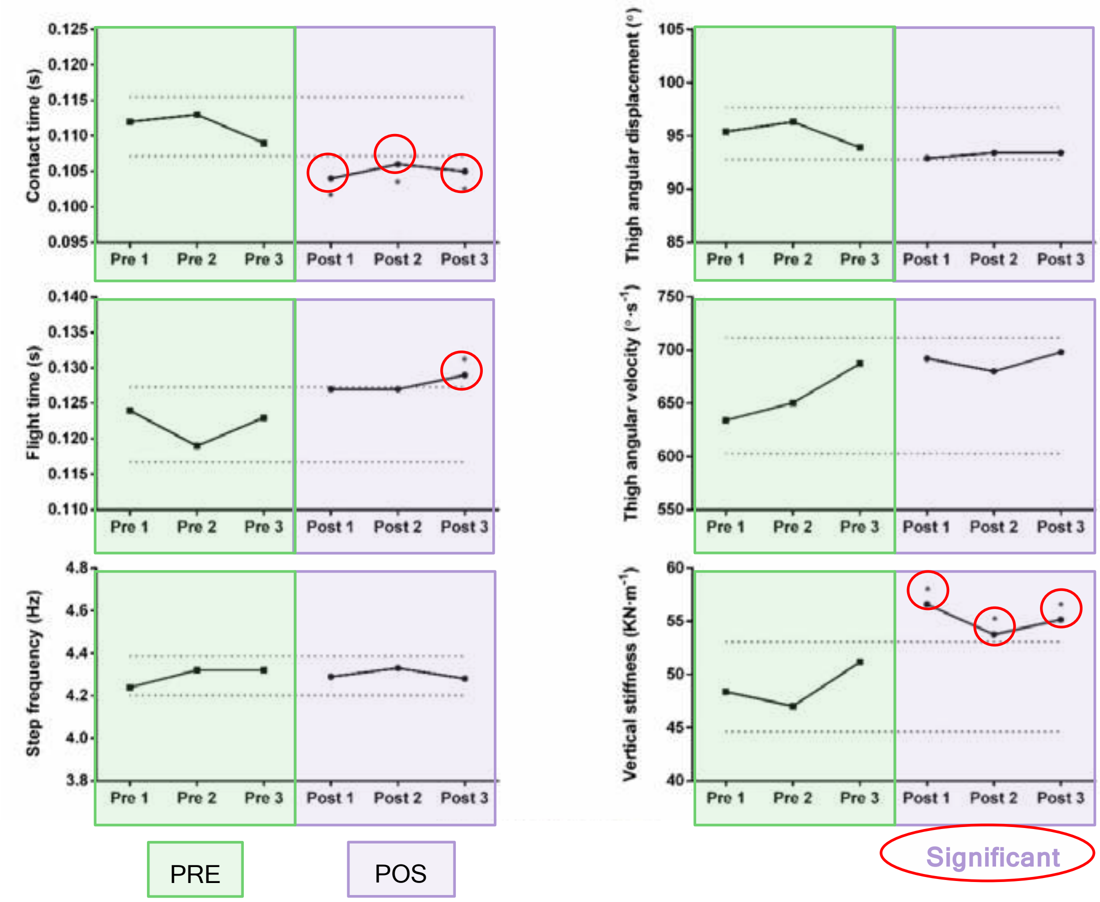
Appendix



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0.110
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0.095
Flight time (s)
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0.130
0.125
0.120
0.115
0.110
Step frequency (Hz)
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4.4
4.2
4.0
3.8
Thigh angular displacement (°)
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100
95
90
85
Thigh angular velocity (°·s⁻¹)
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700
650
600
550
Vertical stiffness (KN·m⁻¹)
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55
50
45
40
Pre 1
Pre 2
Pre 3
Post 1
Post 2
Post 3
PRE
POS
Significant