The effects of a 4-week mesocycle of barbell back squat or barbell hip thrust strength training upon isolated lumbar extension strength

Alexander Hammond [1] , **Craig Perrin** [1] , **James Steele** [1] , **Jürgen Giessing** [2] , **Paulo Gentil** [3] , **James P Fisher** [Corresp. 1]

[1] Sport, Health and Social Sciences, Southampton Solent University, Southampton, UK

[2] Institute of Sport Science, Universität Koblenz-Landau, Landau, Germany

[3] Faculty of Physical Education and Dance, Universidade Federal de Goiás, Goiania, Brazil

Corresponding Author: James P Fisher
Email address: james.fisher@solent.ac.uk

Objectives: Common exercises such as the barbell back squat (BBS) and barbell hip thrust (BHT) are perceived to provide a training stimulus to the lumbar extensors. However, to date there have been no empirical studies considering changes in lumbar extension strength as a result of BBS or BHT resistance training interventions. **Purpose:** To consider the effects of barbell back squat (BBS) and barbell hip thrust (BHT) resistance training programmes upon isolated lumbar extension (ILEX) strength. **Methods:** Trained male subjects (n=14; 22.07 ± 0.62 years; 179.31 ± 6.96 cm; 79.77 ± 13.81 kg) were randomised in to either BBS (n=7) or BHT (n=7) groups and performed 2 training sessions per week during a 4-week mesocycle using 80% of their 1RM. All subjects were tested pre- and post-intervention for BBS and BHT 1RM as well as isometric ILEX strength. **Results:** Analyses revealed that both BBS and BHT groups significantly improved both their BBS and BHT 1RM, suggesting a degree of transferability. However, the BBS group improved their BBS 1RM to a greater degree than the BHT group (*p*=0.050; ~11.8kg/10.2% vs. ~8.6kg/7.7%, respectively). And the BHT group improved their BHT 1RM to a greater degree than the BBS group (*p*=0.034; ~27.5kg/24.8% vs. ~20.3kg/13.3%, respectively). Neither BBS nor BHT groups significantly improved their isometric ILEX strength. **Conclusions:** The present study supports the concept of specificity, particularly in relation to the movement mechanics between trunk extension (including pelvic rotation) and ILEX. Our data suggests that strength coaches personal trainers, and trainees can self-select multi-joint lower body trunk extension exercises based on preference or variety. However, evidence suggests that neither the BBS nor BHT exercises can meaningfully increase isolated lumbar extension strength. Since strengthening these muscles might enhance physical and sporting performance we encourage strength coaches and personal trainers to prescribe ILEX exercise.

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Running Title: Back squat and Hip Thrust for low-back strength

Original research article

Alexander Hammond[1], Craig Perrin[1], James Steele[1], Jürgen Giessing[2], Paulo Gentil[3], James Peter Fisher[1]

[1] School of Sport, Health and Social Science, Southampton Solent University, UK

[2] Institute of Sport Science, University of Koblenz-Landau, Germany

[3] Faculty of Physical Education and Dance, Federal University of Goias, Brazil

Corresponding Author:
James Peter Fisher
School of Sport, Health and Social Science
Southampton Solent University
East Park Terrace
Southampton
UK
Tel: +44 2382 013163
Email: james.fisher@solent.ac.uk

Co-Author contact details:
Alexander Hammond (alex.hammond01@btinternet.com)
Craig Perrin (craig.perrin@solent.ac.uk)
James Steele (James.steele@solent.ac.uk)
Jürgen Giessing (giessing@uni-landau.de)
Paulo Gentil (paulogentil@hotmail.com)

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Abstract

Objectives: Common exercises such as the barbell back squat (BBS) and barbell hip thrust (BHT) are perceived to provide a training stimulus to the lumbar extensors. However, to date there have been no empirical studies considering changes in lumbar extension strength as a result of BBS or BHT resistance training interventions. **Purpose:** To consider the effects of barbell back squat (BBS) and barbell hip thrust (BHT) resistance training programmes upon isolated lumbar extension (ILEX) strength. **Methods:** Trained male subjects (n=14; 22.07 ± 0.62 years; 179.31 ± 6.96 cm; 79.77 ± 13.81 kg) were randomised in to either BBS (n=7) or BHT (n=7) groups and performed 2 training sessions per week during a 4-week mesocycle using 80% of their 1RM. All subjects were tested pre- and post-intervention for BBS and BHT 1RM as well as isometric ILEX strength. **Results:** Analyses revealed that both BBS and BHT groups significantly improved both their BBS and BHT 1RM, suggesting a degree of transferability. However, the BBS group improved their BBS 1RM to a greater degree than the BHT group (p=0.050; ~11.8kg/10.2% vs. ~8.6kg/7.7%, respectively). And the BHT group improved their BHT 1RM to a greater degree than the BBS group (p=0.034; ~27.5kg/24.8% vs. ~20.3kg/13.3%, respectively). Neither BBS nor BHT groups significantly improved their isometric ILEX strength. **Conclusions:** The present study supports the concept of specificity, particularly in relation to the movement mechanics between trunk extension (including pelvic rotation) and ILEX. Our data suggests that strength coaches personal trainers, and trainees can self-select multi-joint lower body trunk extension exercises based on preference or variety. However, evidence suggests that neither the BBS nor BHT exercises can meaningfully increase isolated lumbar extension strength. Since strengthening these muscles might enhance physical and sporting performance we encourage strength coaches and personal trainers to prescribe ILEX exercise.

Key words: 1-repetition maximum, isometric, torque, specificity,

INTRODUCTION

Low-back strength, particularly as a component part of core strength and stability, retains an importance in athletic performance and thus strength and conditioning within sports (Hibbs, et al. 2008). Indeed, the strength and cross-sectional area of the erector spinae and quadratus lumborum have been suggested to explain 50% of the variance in sprint speed over 20m (Kubo, et al. 2011), a substantial contribution for an inconspicuous muscle during sprinting. Furthermore, elevated forces through the lumbar spine whilst blocking in American football, as well as during a golf swing, suggest that improving lumbar strength might be beneficial towards both enhancing performance and reducing risk of injury (Gatt, et al. 1997; Gluck, et al. 2008). Finally, simulation research suggests erector spinae weakness results in compensation from synergistic muscles, potentially causing an earlier onset of fatigue and exacerbating low-back pain and performance decrements (Raabe and Chaudhari, 2018).

Research has supported that common exercises such as the barbell back squat (BBS) place considerable stress on the lumbar musculature (Cholewicki, et al. 1991) supported by the high levels of activation of the lumbar muscles when measured by electromyography (EMG; Hamlyn, et al. 2007; Yavuz, et al. 2015). Indeed, as it is thought the lumbar extensor musculature is heavily involved in the BBS, many strength and conditioning coaches advocate the use of the barbell back squat (BBS) and deadlift exercises with a view to provide a training stimulus and increase the strength of the lumbar muscles (Mayer, et al. 2008).

Nevertheless, whilst the BBS exercise appears to be a hypothetical solution to strengthening the lumbar muscles (although no empirical evidence exists), alternative and perhaps superior exercises may be available. An exercise growing in popularity is the barbell hip thrust (BHT), which has been shown to produce greater EMG amplitude in the hamstring and gluteal muscles when compared to the BBS exercise (Contreras, et al. 2015). The BHT has also been shown to be associated with performance markers such as acceleration (r=0.93; Loturco, et al. 2018). Furthermore, Contreras, et al. (2017) recently compared 6-weeks of strength training using either a front squat or BHT exercise on performance markers in adolescent males. The authors reported favourable effect sizes for the BHT for 10m and 20m sprint times, and isometric mid-thigh pull, whereas the front squat exercise produced favourable effect sizes for the vertical jump and front squat 3RM. Andersen, et al. (2018) compared EMG activity during the barbell deadlift, hex bar deadlift and BHT exercises. Although there were no statistically significant differences between the three exercises for erector spinae muscle activation, the BHT did elicit the greatest muscle activation during the concentric phase of the movement when the hip angle was approaching or exceeding 180 degrees. The authors suggest that the BHT likely promotes increased muscle activation in the upper phase due to the increased hip torque requirement in the end range of this horizontally loaded exercise. In contrast, during a deadlift or BBS exercise the lumbo-pelvic complex reaches complete hip extension in a vertical anatomical position meaning the forces produced by the barbell load the skeletal system and likely produce lower muscular activation.

However, the BBS and BHT both involve the lumbo-pelvic complex in a compound movement integrating both hip- and lumbar-extension (i.e. trunk extension). Previous research considering both resistance machines (Graves, et al. 1994) and free-weight exercise (the Romanian deadlift; Fisher, et al. 2013) has suggested that trunk extension exercise (hip- and lumbar-extension) that permits rotation of the pelvis is not efficacious in increasing isolated lumbar extension strength. This is likely a result of hamstring and gluteal contribution via pelvic rotation, rather than isolated lumbar extension. Indeed, research has supported that there is significantly greater activation of the lumbar multifidus during back extension when the pelvis is stabilized (San Juan, et al. 2005), and in addition, muscle activation of the gluteus maximus and biceps femoris is decreased (Da Silva, et al. 2009). However, contrasting evidence does exist to support trunk extension tasks in producing isolated lumbar extension fatigue. For example, Edinborough, et al. (2016) reported that performing kettlebell swings produced transient fatigue in isolated lumbar extension (ILEX) strength, hypothesising that performing the kettlebell swing exercise as part of a training programme might produce a chronic training effect.

Despite this, a recent study (Androulakis-Korakakis, et al. 2018) has reported that ILEX strength does not differ between recreationally trained males and both competitive and non-competitive powerlifters; a population who regularly train with exercises such as the BBS. Currently reviews of the efficacy of different exercise approaches upon ILEX strength suggest that evidence is limited with respect to many approaches, yet that an ILEX exercise may be most efficacious (Steele, et al. 2015). However, devices for this are expensive, not readily available, and as such, the consideration of cheaper and accessible alternatives to ILEX exercise for strengthening the lumbar extensors should be considered.

To date, no empirical studies have assessed the efficacy of the either the BBS exercise or the BHT upon isolated lumbar extension strength. Thus, the aim of the present study was to consider the efficacy of a 4-week mesocycle of either BBS or BHT exercise in increasing ILEX strength.

METHODS

A randomised trial, research design was used whereby fourteen trained males were randomised in to either BBS (*n*=7) or BHT (*n*=7) training. Both groups were assessed pre- and post-intervention for BBS and BHT maximal strength (1-repetition maximum; 1RM) as well as isometric ILEX strength. The study was approved by the University Health, Exercise, and Sport Science (HESS) ethical review board at the corresponding authors' institution (ID No. 669).

Using convenience and snowball sampling methods, fourteen trained males were recruited. Subjects were required to have >6 months resistance training (RT) experience, and currently be performing a structured RT programme with at least one session per week including the use of BBS exercise and BHT exercise and have no history of low-back pain. Written informed consent was obtained from all subjects prior to participation. Subjects were randomised using a computer randomisation program to one of two groups; BBS (*n*=7), or BHT (*n*=7). Subjects were asked to refrain from any exercise away from the supervised sessions. Participant demographics are included in table 1.

INSERT TABLE 1 AROUND HERE

A power analysis of previous research, using similar study design and asymptomatic subjects (Contreras, et al. 2017; Styles, et al. 2016) was conducted to determine sample size (*n*). The effect size (ES) was calculated for both studies using Cohen's *d* (1992), producing a mean ES of 1.67 for BBS and BHT strength increases. Participant numbers were calculated using equations from Whitley and Ball (2002) revealing each group required 7 subjects to meet required β power of 0.8 at an α value of $p<0.05$. It should be noted that the study was powered for the identification of within group changes (two tailed) in outcomes and between group comparisons were a secondary outcome. Based upon sensitivity analysis for between group comparisons for the analysis detailed below the study was powered to identify at most a large between group effect size of $f = 0.82$.

Subjects attended a preliminary session where they were assessed on their familiarity with both BBS and BHT exercises and verified their ability to perform them safely with correct technique. They also attended a familiarisation session for the MedX lumbar extension machine (MedX, Ocala, FL, USA) used for measuring isometric isolated ILEX, where subjects performed a testing session in the format detailed below. The ILEX machine (Figure 1) has been demonstrated as valid (Graves, et al. 1990; 1994) and reliable (r=0.94-0.98; Pollock, et al. 1989) and the details of which have been described elsewhere (Graves, et al. 1990).

INSERT FIGURE 1 AROUND HERE

Subjects reported to the laboratory having refrained from exercise other than that of daily living for at least 48 hours before baseline testing, and at least 48 hours before post-intervention testing.

Maximum strength testing was consistent with recognized guidelines established by the NSCA (Baechle and Earle, 2008). Prior to testing, subjects performed a general warm-up consisting of 5 minutes cycling at 60-70 rpm and 50w. Next, a specific warm-up set of the prescribed exercise for 5 repetitions was performed at ~50% 1RM followed by 1 to 2 sets of 2–3 repetitions at a load corresponding to ~60–80% 1RM. Subjects then performed 1 repetition sets of increasing weight for 1RM determination. The external load was adjusted by ~5-10% in subsequent attempts until the subject was unable to complete 1 maximal muscle action. The 1RM was considered the highest external load lifted. A 3- to 5-minute rest was provided between each attempt. All 1RM determinations were made within 5 attempts.

The BBS 1RM was completed first, followed by the BHT 1RM, with a 20-minute rest interval between exercises to allow for sufficient recovery. As per Contreras, et al. (2015), the BHT was performed by having subjects' upper back on a bench with the feet positioned wider than shoulder width and toes pointed forwards or slightly outwards. The barbell was padded with a thick bar pad and placed over the subjects' hips. Subjects were instructed to thrust the bar upwards while maintaining a neutral spine and pelvis. Full extension of the hips (180˚) was required for a successful lift.

On a separate day following no less than 72 hours rest, subjects attended the laboratory for ILEX strength testing. Subjects were seated upright with their pelvis secured by a restraint pad across the anterior, upper thigh, and another across the thigh just superior to the knee. These pads were fixed tightly to ensure the effort produced was from the lumbar musculature only and not from the pelvis or thighs, isolating the lumbar extensors. A counter-weight was used to balance the mass of the upper body and the effects of gravity on the upper body. All subjects were assessed for range of motion (ROM) and performed a dynamic warm-up with a load equating to 90lbs / ~41kg and three submaximal isometric tests at full flexion, full extension and a mid-range position. Maximal isometric testing was then performed at 7 joint angles (0˚, 12˚, 24˚, 36˚, 48˚, 60˚ and 72˚ of extension) where subjects were encouraged to gradually achieve maximal effort over 2-3 seconds and to maintain the maximal contraction for a further 1 second. The torque produced was measured by a load cell attached to the movement arm. Subjects rested for 5-10 seconds between tests at different joint angles. ILEX strength was considered as a ‘strength index’ (SI) calculated as the area under the torque curve from multiple angle testing in order to provide a composite measure of overall changes in strength across the range of motion. Based upon between day repeated test-retest data from prior studies in our lab (Edinburough, et al. 2016; Stuart, et al. 2018) we determined the typical error of measurement for the SI as 1659.51 Nm·degrees (95%CIs = 1316.46 to 2317.17 Nm·degrees) using Hopkins (2015) spreadsheets for reliability.

Both the BBS and BHT participant groups attended 2 resistance training session per week, for a 4-week mesocycle. During these sessions each participant performed 3 sets using 80% of their 1RM (mean=8RM; range=6-10RM) in a controlled, non-explosive manner (2 seconds concentric, 4 seconds eccentric; monitored by a supervisor using a metronome) in order to maximise muscle tension and eliminate momentum. All sets were performed to momentary failure (e.g. the inability to complete the concentric phase of a repetition despite maximal effort; Steele, et al. 2017) whereby if participants completed a repetition then they attempted the successive repetition until they could not complete the concentric phase of the movement. Subjects were asked to confirm maximal effort using a CR-10 rating of perceived exertion (RPE) scale (Day, et al. 2004), and were instructed to rest 3-5 minutes between sets. All training sessions were supervised one-to-one and attempts were made to increase the load lifted each week whilst maintaining the target repetition range. No injuries were reported and adherence to the programme was 100% for both groups.

The independent variable was the group (BBS or BHT) and dependent variables changes (i.e. post-test minus pre-test values) in BBS 1RM, BHT 1RM, and SI. Analysis of covariance (ANCOVA) was used for between group comparisons in dependent variables with baseline measures as covariates (i.e., pre-intervention BBS 1RM, BHT 1RM, and SI). Point estimates were calculated along with the precision of those estimates using 95% confidence intervals (CI) for within group adjusted means. The 95%CIs were further interpreted to indicate that significant within group changes occurred if the upper or lower limits do not cross zero. The software used was SPSS (version 23, IBM Corp, Portsmouth, UK) and the cut off for significance was $p < 0.05$. Gardner-Altman plots were also produced using Estimation Statistics (Claridge-Chang and Assam, 2016) for data visualization. Visual inspection of the data using boxplots revealed 2 outliers (determined using the interquartile rule) for both change in BBS 1RM (in the BHT group) and change in BHT 1RM (in the BBS group) and further Shapiro-Wilk tests confirmed that data did not meet assumptions of normality of distribution for the groups containing the outliers (change in squat 1RM, BHT group p < 0.001; change in BHT 1RM, BBS group $p < 0.001$). Thus, for these variables, due to the significant deviations from normality of distribution combined with the relatively small sample size, the data were rank transformed prior to performing ANCOVA (Olejnik, et al. 1984). All results are reported in the units of measurement for each test.

RESULTS

The 95%CIs for changes did not cross zero for change in squat 1RM or change in BHT 1RM in either group and thus both groups had significant within-group improvements in these outcomes. The 95%CIs for changes in SI did not cross zero for the BHT group suggesting a significant change; however, change in SI did not exceed typical error of measurement for either group and so is unlikely to be a meaningful change. Between group comparisons using ANCOVA revealed significant differences for change in squat 1RM ($F_{(1,11)} = 5.240$, $p = 0.043$), change in BHT 1RM ($F_{(1,11)} = 6.673$, $p = 0.025$), but not for change in SI ($F_{(1,11)} = 1.541$, $p = 0.240$). Table 1 shows pre- and post-intervention results, unadjusted means (±SD) or medians (±IQR) for rank transformed variables for changes in each outcome measure, and 95%CIs for the changes. For visual depiction of results, Gardner-Altman plots of changes for each outcome are presented in figure 2.

INSERT FIGURE 2 AROUND HERE

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DISCUSSION

To the authors knowledge this is the first study to investigate the effects of BBS and BHT strength training upon ILEX strength. As such this research adds to a dearth of literature considering exercise protocols to improve lumbar extension strength.

We should first consider the efficacy of the training routine for the specific exercises. Our analyses revealed that the BBS training group significantly improved BBS and BHT 1RM by averages of ~11.8kg/10.2%, and ~20.3kg/13.3%, respectively. Furthermore, the BHT training group significantly improved BBS and BHT 1RM by averages of ~8.6kg/7.7% and ~27.5kg/24.8%, respectively. Whilst specificity meant that both groups improved their strength to a significantly greater degree on the exercise they used during training (e.g. the BBS group improved their BBS 1RM to a greater degree than the BHT group, and the BHT group improved their BHT 1RM to a greater degree than the BBS group), the present data suggests a degree of transferability between exercises.

However, our data suggests that neither the BBS nor BHT resistance training exercises serve to improve ILEX strength, since the pre- to post-intervention changes did not exceed the typical error of measurement. Recent research serves to support our findings in context of the BBS exercise. For example, Vigotsky, et al. (2018), recently reported no relationship between BBS 1RM and isometric spinal extension strength. In their discussion, Vigotsky, et al. suggested that, during a BBS exercise, *"the spinal erectors need only resist the net joint moment as well as a small abdominal co-contraction, which does not necessarily increase with load"*. Additionally, Androulakis-Korakkakis, et al. (2018) recently reported isometric lumbar extension torque and BBS 1RM values for non-competitive powerlifters (NCPL) and competitive powerlifters (CPL). The data suggested that, despite large and significant differences in BBS 1RM (NCPL=177.0kg, CPL=215.2kg), there were no differences in ILEX strength (SI;

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NCPL=22864N·m, CPL=22850N·m). Indeed, data from the present study produced similar ILEX strength values 20000-21820N·m supporting that beyond a certain threshold the lumbar extensors might not be required to increase in strength to aid BBS performance. However, despite the lack of association between ILEX strength and BBS strength, and the existence of an association between performance markers and the BBS, it is not wholly clear whether *increasing* lumbar extension strength through isolated training might also increase performance. The absence of specific isolated lumbar extensor training may be suboptimal for developing athletic performance. Indeed, Fisher et al. (2013) have shown that ILEX resistance training can increase Romanian deadlift 1RM. Further research is required though to examine ILEX training interventions upon performance outcomes, including BBS strength and sporting performance.

The BHT represents a more contemporary, and thus limited, area of exercise science research. Certainly evidence has suggested that the BHT might be an efficacious exercise for improving sprint performance and mid-thigh pull (Contreras, et al. 2017), and data supports considerable muscle activation of the hamstring and gluteal muscles (Contreras, et al. 2015). In addition, research has suggested greater erector spinae muscle activation for the BHT compared to the barbell- and hex bar-deadlifts (Andersen, et al. 2018), and as noted improving ILEX strength can serve to improve Romanian deadlift 1RM (Fisher, et al. 2013). However, the present study suggests that training, and indeed enhancing 1RM for the BHT exercise does not improve ILEX strength. This specificity of adaptation is further supported as Fisher, et al. (2013) also reported a group training using the Romanian deadlift increased their Romanian deadlift 1RM significantly but failed to increase their ILEX strength.

With the above in mind it appears that, despite large increases in BBS and BHT 1RM as a result of the respective resistance training programmes, ILEX strength is likely not improved by either exercise. Previous research has suggested that the use of exercise where pelvic rotation is permitted does not improve isolated lumbar extension strength (Graves, et al. 1994; Fisher, et al. 2013). In context, it might

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be that the gluteal and hamstring muscles serve to provide trunk-extension (e.g. hip- and lumbar-extension), and as a result both BBS and BHT resistance training produce strength increases in these muscles which can transfer to improve performance between the respective exercises. However, as a result of the pelvic rotation through trunk extension (and thus the dominance of the gluteal and hamstring muscles), neither BBS nor BHT exercises appear to provide a sufficient training stimulus to the lumbar extensors. This is fitting with previous research which has reported no relationship between trunk extension performance (assessed via Biering-Sorensen test) and isolated lumbar extension strength in both asymptomatic persons as well as those symptomatic with chronic low back pain (Conway, et al. 2017). Nonetheless, some tasks performed with pelvic rotation can induce lumbar fatigue suggesting a role for this muscle during movement, for example kettlebell swings (Edinborough, et al. 2016). Though the present data suggests that both the BBS and BHT do not improve lumbar extension strength, and previous data suggests the Romanian deadlift also lacks efficacy (Fisher, et al. 2013), further research should consider other exercises such as the kettlebell swings in training interventions.

We should, of course, remember that exercises such as the BBS are not performed solely with the intent of strengthening the lumbar extensors, and that this exercise shows a strong relationship to athletic performance markers such as sprint speed (r=0.71-0.94) and vertical jump (r=0.78; Wisløff, et al. 2004). However, previous review has questioned the need for adding single-joint exercise to a resistance training programme since muscular adaptations appear similar to when performing only multi-joint exercises (Gentil, et al. 2017). As mentioned above we might consider trunk extension (e.g. hip- and lumbar-extension) to be multi-joint, and isolated lumbar extension to be more similar to single-joint movements (though strictly speaking it is a multi-joint movement due to the vertebral segments). However, in light of the previous research as well as present findings, it appears that multi-joint exercises which include trunk extension (such as the BBS and BHT) are not sufficient to strengthen the

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lumbar extensors. As such, though multi-joint movements may be sufficient for appendicular muscular adaptations (Gentil, et al. 2017), we would suggest that both athletes and lay persons consider supplementing existing training practices with specific ILEX exercise to strengthen the lumbar muscles.

Whilst the present study provides useful data and guidance as to the efficacy of different exercises in strengthening the lumbar extensors, we should accept the limitation that we did not include an ILEX training group which might reflect the possible comparative increases in ILEX strength. Previous research has demonstrated that isometric ILEX strength can increase considerably as a result of once weekly training sessions using 80% MVC over 10-weeks (strength index change=4353N·m; Fisher, et al. 2013). Furthermore, interventions performed once a week over 6 week durations have been shown to produce significant increases in lumbar extension strength using both single- and multiple-sets in trained males (single set = 1854Nm, multiple set = 2415Nm; Steele, et al. 2015), and with both heavier-loads (80% MVC) and lighter-loads (50% MVC) in recreationally active males and females (strength index change; 80% MVC = 2891N·m, 50% MVC = 2865N·m; Fisher, et al. 2018). As such, had we included an ILEX training group, we would expect 8 sessions performed over 4 weeks to have likely produced significant and meaningful increases in isometric ILEX strength. A further limitation might be the brevity of the present 4-week strength mesocycle. Whilst we contest that this is fitting with training practices, we accept that many athletes and persons undertake longer mesocycles, or continue exercises across multiple phases of periodisation. Future research might consider the transference of adaptations as a result of continued BBS or BHT resistance training through strength, power and/or hypertrophy loading phases. Lastly, this study was relatively small and primarily powered to identify within group changes in outcomes. Though we did identify between group differences in both BBS and BHT 1RM changes future research with greater sample sizes should examine this with greater statistical power.

CONCLUSION

The present study provides support for the concept of specificity, particularly in relation to the movement mechanics between trunk extension (including pelvic rotation) and isolated lumbar extension. Our data suggests that both the BBS and BHT exercises produce meaningful increases in strength which might transfer between lower-body trunk extension exercises. This allows strength coaches, personal trainers, and trainees to self-select multi-joint lower body trunk extension exercises based on preference or variety. However, evidence suggests that neither the BBS nor BHT exercises, nor indeed any exercise allowing pelvic rotation through trunk extension, can meaningfully increase ILEX strength. Since strengthening these muscles might enhance physical and sporting performance we encourage strength coaches and personal trainers to supplement existing practices by prescribing specific ILEX exercise.

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Figure 1 (on next page)

MedX Lumbar Extension Machine showing restraint system

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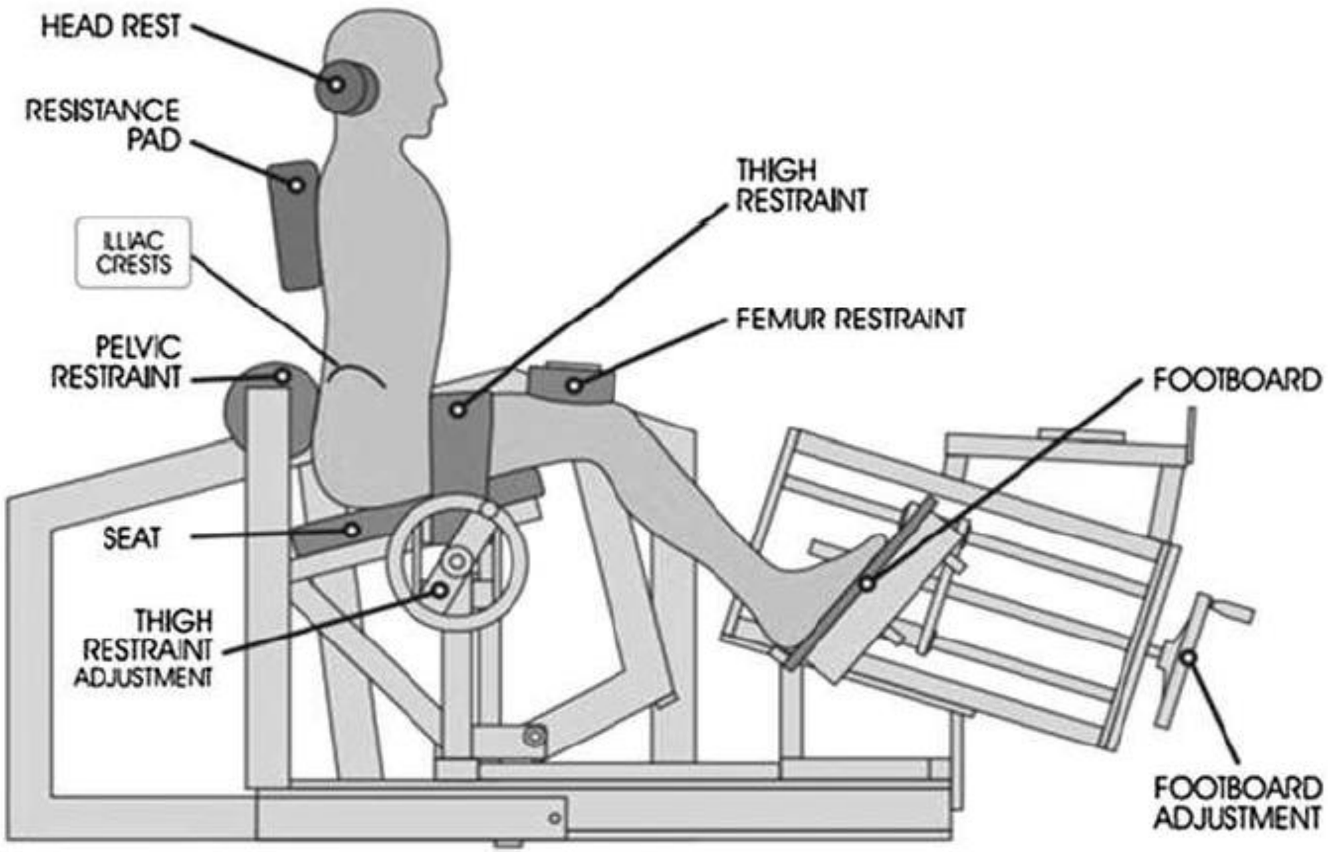

Figure 1. MedX Lumbar Extension Machine showing restraint system.

Figure 2 (on next page)

Gardner-Altman Plots - all participants

Figure shows changes for each outcome for all participants

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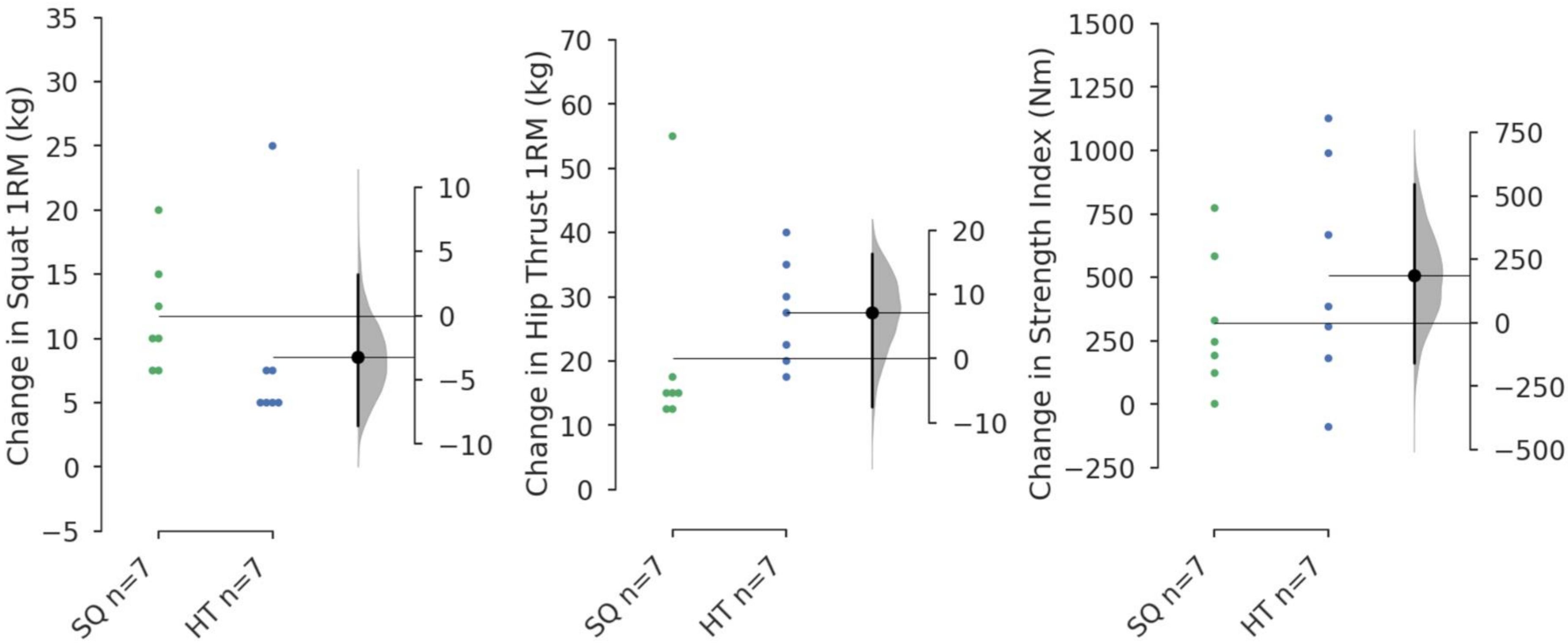

Change in Squat 1RM (kg)
35
30
25
20
15
10
5
0
−5
10
5
0
−5
−10
SQ n=7
HT n=7
Change in Hip Thrust 1RM (kg)
70
60
50
40
30
20
10
0
20
10
0
−10
SQ n=7
HT n=7
Change in Strength Index (Nm)
1500
1250
1000
750
500
250
0
−250
750
500
250
0
−250
−500
SQ n=7
HT n=7

Table 1 (on next page)

Participant Characteristics

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Table 1. Participant Characteristics

Characteristic	Back Squat (*n*=7)	Barbell Hip Thrust (*n*=7)
Age (years)	21.71 ± 0.45	22.43 ± 0.49
Height (cm)	181.61 ± 4.63	177 ± 7.61
Body mass (kg)	76.49 ± 9.09	83.06 ± 15.81

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Table 2(on next page)

Pre- and Post-intervention 1-repetition maximum (1RM; means ±SD) and isolated lumbar extension strength (N·m), changes, and 95% confidence intervals (CIs)

Data for back squat 1RM and hip thrust 1RM are presented as medians (±IQR), whereas data for isolated lumbar extension strength is presented as mean (±SD)

Table 2. Pre- and Post-intervention 1-repetition maximum (1RM; means ±SD) and isolated lumbar extension strength (N·m), changes, and 95% confidence intervals (CIs)

Group	Variable	Pre-intervention	Post-intervention	Changes	95%CIs for change
Back squat group (n=7)	Back Squat 1RM (kg)	115.0±35.0	122.5±27.5	10.0±7.5	7.6 to 15.9
	Hip Thrust 1RM (kg)	160.0±42.5	180.0±50.0	15.0±5.0	6.1 to 34.6
	Isolated Lumbar Extension Strength (N.m)	19670±1974	20000±1847	321±270	25 to 600
Hip Thrust group (n=7)	Back Squat 1RM (kg)	110.0±7.5	117.5±17.5	5±2.5	1.8 to 15.4
	Hip Thrust 1RM (kg)	162.5±25.0	187.5±42.5	27.5±15.0	19.9 to 35.1
	Isolated Lumbar Extension Strength (N.m)	21310±2950	21820±2998	509±439	231 to 856

Note: Data for back squat 1RM and hip thrust 1RM are presented as medians (±IQR), whereas data for isolated lumbar extension strength is presented as mean (±SD)