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Manuscript Title: The validity and reliability of a customized rigid supportive harness during Smith Machine back squat exercise

Short Title: Harness back squat validity and reliability

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ABSTRACT

While the back squat exercise is commonly prescribed to both athletic and clinical populations, individuals with restricted glenohumeral mobility may be unable to safely support the bar on the upper trapezius using their hands. The aims of this study were to investigate the validity and reliability of a back squat variation using a rigid supportive harness that does not require unrestricted glenohumeral mobility for quantifying 1-repetition maximum (1RM). Thirteen young men (age = 25.3 ± 4.5 yr, height = 179.2 ± 6.9 cm, body mass = 86.6 ± 12.0 kg) with at least two years resistance training experience volunteered to participate in the study. Subjects reported to the lab on three occasions, each separated by one week. During testing sessions, subjects were assessed for 1RM using the traditional back squat (session 1) and harness back squat (HBS; sessions 2 and 3) exercises. Mean 1RM for the traditional back squat, and two testing sessions of the HBS (HBS₁ and HBS₂) were 148.4 ± 25.0 kg, 152.5 ± 25.7 kg and 150.4 ± 22.6 kg, respectively. Back squat and mean HBS 1RM scores were very strongly correlated (r = 0.96; p < 0.001). There were no significant differences in 1RM scores between the three trials. The test-retest 1RM scores with the HBS demonstrated high reliability, with an intraclass correlation coefficient of 0.98 (95% confidence interval [CI] = 0.93-0.99), and a coefficient of variation of 2.6% (95% CI = 1.9-4.3). Taken together, these data suggest that the HBS exercise is a valid and reliable method for assessing 1RM in young men with previous resistance training experience, and may be useful for individuals with restricted glenohumeral mobility.

Key Words: resistance exercise, maximum strength, glenohumeral instability, training experience
INTRODUCTION

Resistance training is commonly undertaken by both athletic and clinical populations to increase muscular size and strength, and for health-related benefits such as increases in bone mass, reduced blood pressure and increases in connective tissue cross-sectional area (3). The parallel back squat is one of the most frequently used exercises in the field of strength and conditioning (28). The back squat has biomechanical and neuromuscular similarities to a range of athletic and everyday movements, and is recognized to elicit greater levels of muscle activation compared with leg press and leg extension exercises, as well as effectively activating the trunk stabilizers (4). As a result, the back squat is included as a pivotal exercise in many resistance training programs that are designed to enhance both sports performance in athletes, and quality of life in the general population (13,16,28).

During the traditional back squat, both shoulders are maintained in position of abduction combined with external rotation to support the bar on the upper trapezius with the hands (2,11,14). This position maximally stresses the anterior capsule of the glenohumeral joint (15,26), potentially leading to anterior glenohumeral hyperlaxity and, over time, instability (i.e. excessive movement of the humeral head anteriorly on the glenoid fossa) (5). As a result, individuals prone to anterior glenohumeral hyperlaxity or instability should avoid the abducted and externally rotated shoulder position (11,18). Furthermore, individuals with restricted glenohumeral range of motion (ROM), such as those recovering from shoulder surgery, may experience pain when the upper extremities are maintained in this position (15). This restricted glenohumeral ROM may be categorised by limitations in the ability to achieve or maintain desired positioning of the glenohumeral complex during movement. A
variation of the back squat exercise that does not necessitate this glenohumeral position is of particular interest for these individuals.

The front squat exercise may be a viable substitute for those suffering anterior glenohumeral instability or restricted ROM (11,14). While the maximal amount of weight an individual can lift with this variation is typically less (~60-80%) than for the back squat (14,16), comparison of the back and front squat using an inverse dynamics approach has reported no differences in shear forces at the knee or in the degree of muscle activation, though compressive forces and knee extensor moments were larger in the back squat (16). While this suggests that at equivalent relative loads, the front squat elicits a similar biomechanical stimulus to the back squat, it should be noted that novice lifters might lack the required flexibility in the wrist and shoulder to maintain correct hand and arm positioning during the front squat (2). Furthermore, special populations (i.e. individuals with amputation) may be unable to support the bar with the hands across the anterior deltoids and clavicles when performing the front squat. Thus, an alternative squat exercise that allows an individual to lift loads similar to their back squat potential, while not compromising glenohumeral stability, is worthy of research attention.

The loading applied during resistance exercise is widely accepted as one of the most important training variables to consider during resistance training programs (30). Training loads are often prescribed relative to the heaviest weight that can be lifted for one complete repetition (1-repetition maximum [1RM]) (3,30). Testing 1RM prior to and following a training program also enables the adaptive strength response to be quantified. However, to ensure that the prescription of loads and pre/post training monitoring are reflective of an individual’s true 1RM, it is important that the reliability of testing measures is established. Therefore, the primary purpose of this
investigation was to assess the validity of a back squat variation using a customised rigid supportive harness in a Smith Machine to measure maximum lower body strength. The secondary purpose of this study was to analyse the intersession reliability of 1RM testing using this squat variation. As previous research has reported no significant difference between back squat 1RM scores using either free weights or a Smith Machine in young men (6), it was hypothesized that similar 1RM scores would be achieved using the traditional back squat and the harness back squat (HBS).

METHODS

Experimental Approach to the Problem

The back squat exercise is widely used to test maximum lower body strength and to train for hypertrophic and strength gains (28). The use of a supportive harness that allows individuals with contraindicated or restricted glenohumeral ROM to perform the back squat exercise in a Smith Machine without supporting the bar using their hands is of interest for both athletic and clinical populations. The current study firstly assessed the validity of 1RM testing using a customized rigid supportive harness (Manta Ray, Advanced Fitness Inc., Cincinnati, USA) during back squat exercise in a Smith Machine. Criterion validity was established by comparing 1RM scores using a traditional back squat to scores when using the HBS. Secondly, the intersession reliability of 1RM scores using the HBS was assessed by comparing 1RM scores from two separate testing sessions.

Subjects

Thirteen healthy male subjects (age = 25.3 ± 4.5 yr, height = 179.2 ± 6.9 cm, body mass = 86.6 ± 12.0 kg) volunteered to participate in this study. All subjects had at
least two years resistance training experience, and were free of any musculoskeletal disorders. In order to participate, subjects were required to demonstrate pain-free glenohumeral ROM sufficient to perform the traditional back squat. Prior to commencement of the study, all subjects were provided with information detailing the purpose and requirements of the research, provided informed consent and were screened for medical contraindications. Sample size was calculated based on the assumption of a large effect size (0.8) with an α level of 0.05, which determined that at least 10 subjects were required. The study and its methods were approved by the institutional Human Ethics Committee.

**Procedures**

Subjects reported to the laboratory on three occasions, each separated by one week. Subjects were instructed to abstain from alcohol and caffeine for 24 hours prior to each testing session, and to avoid any strenuous physical activity for the duration of the study. During the first visit, subjects performed 1RM testing of the back squat exercise following established protocol (12). Briefly, subjects were invited to complete a general warm-up (five minutes on a cycle ergometer at a moderate intensity), before performing three specific warm-up sets. These warm-up sets comprised of 10 repetitions at 50% of predicted 1RM weight (as estimated by the subject), 5 repetitions at 70%, and 1 repetition at 90%. The weights used during these warm-up sets were recorded and used for subsequent testing sessions. Following the warm-up, the weight was increased by ~5% and subjects performed a single repetition. This process continued until the subjects were unable to successfully perform a lift, with three minutes rest between attempts. Subjects’ 1RM was defined as their heaviest completed repetition, and was determined within 3-6 sets.
After 10 minutes recovery, subjects were familiarised with a variation of the back squat exercise performed in a Smith Machine using a customized rigid supportive harness. The harness was comprised of a moulded shoulder plate that attached to the bar, a padded posterior column running along the neutral curve of the thoracic spine, and adjustable straps that were tightened under the subjects’ arms and around the torso, level with the sternum (Figure 1). The curve of the posterior column was adjusted to suit each participant. The harness was customized to distribute the weight of the bar evenly across the upper trapezius and posterior deltoids whilst allowing subjects to perform the exercise without supporting the bar with their hands (i.e. hands folded across the chest; Figure 1). For the harness back squat (HBS) exercise, a horizontal line was drawn beneath the Smith Machine, with a second line, perpendicular to the first, indicating the lateral centre of the Smith Machine. To ensure consistent feet placement, subjects’ positioned the posterior edge of their shoes on the horizontal line, with both feet equidistant from the centre line (Figure 1) (21). Once positioned appropriately and with the harness fastened to the bar, subjects unracked the bar from its supportive pegs by extending the knee and hip joints, and a member of the research team rotated the bar to disengage the Smith Machine locking mechanism. Following a completed repetition, a member of the research team rotated the bar to engage the lock, and the subject lowered the bar onto the Smith Machine’s supportive pegs. The second and third visits required subjects to perform 1RM testing, as described above, for the HBS.

***INSERT FIGURE 1 NEAR HERE***
All squatting exercises were assessed according to established criteria (12). Subjects supported the bar on the superior aspect of the trapezius at the base of the neck (back squat) or within the supportive harness (HBS). Slowly flexing at the knees and hips, subjects descended until the front of the thighs were parallel with the ground at the bottom of the squat. A customized elastic stringline was set so that subjects’ superior hamstrings came in contact with the stringline at this bottom position, to signal that appropriate squatting depth had been reached (6,24). This was visually confirmed by two members of the research team, who were positioned adjacent to the participant during each lift. Subjects were also given verbal cues on when they were to halt the down phase, and begin the up phase, of the squat (7). Throughout the movement, heels of the feet remained flat on the ground, the spine was maintained in a neutral position and the head was kept level. If the subject failed to adhere to these criteria during a repetition, the lift was deemed unsuccessful.

**Statistical Analyses**

The mean ± standard deviation was calculated for all variables. Data distribution was tested by normal probability plots and the Kolmogorov-Smirnov test. As 1RM scores for the back squat exercise did not follow a normal distribution, log transformation was performed prior to data analyses using a spreadsheet designed for this purpose (20). The Pearson’s product moment correlation coefficient was calculated between 1RM values for the back squat and the total mean 1RM across both HBS testing sessions (HBS\textsubscript{mean}). Changes in the mean between 1RM for the back squat and HBS were calculated using one-way repeated measures ANOVA. Bland-Altman plots (25) were used to describe the level of agreement between 1RM measurements derived from the back squat and HBS\textsubscript{mean}, and from the repeat 1RM testing sessions using the
HBS (HBS₁ and HBS₂). The intraclass correlation coefficient (ICC), coefficient of variation (CV) and 95% confidence intervals (CI) were calculated using a custom made spreadsheet designed for this purpose (20). The ICC was interpreted as per previous research (9): 0.0-0.2: very weak; 0.2-0.4: weak to low; 0.4-0.7: moderate; 0.7-0.9: strong; 0.9-1.0: very strong. Criterion alpha level for significance was set at \( p \leq 0.05 \). Analyses were performed using SPSS v19.0 (IBM Corporation, Somers, USA).

**RESULTS**

Mean 1RM for the back squat was 148.4 ± 25.0 kg. Mean 1RM for HBS₁ and HBS₂ were 152.5 ± 25.7 kg and 150.4 ± 22.6 kg, respectively. The mean 1RM for HBSmean was 151.5 ± 24.0 kg. Figure 2 illustrates the very strong, significant (\( p < 0.001 \)) relationship between 1RM back squat scores and HBSmean. One-way repeated measures ANOVA revealed no significant differences in 1RM between the means of the back squat exercise and either session of the HBS exercise, nor HBSmean. Furthermore, 1RM scores obtained during HBS₁ and HBS₂ were not significantly different. Figure 3 shows a Bland-Altman plot of 1RM scores with the back squat and HBSmean, and demonstrates a bias and limits of agreement of -3.09 ± 8.73 kg between the two measures.

***INSERT FIGURE 2 NEAR HERE***

***INSERT FIGURE 3 NEAR HERE***

Intersession reliability of 1RM testing with the HBS exercise is expressed with 95% CI. Change in the mean between HBS₁ and HBS₂ was -1.1% (-3.3-1.0). Typical
error, expressed as a CV, was 2.6% (1.9-4.3). The ICC between 1RM scores was 0.98 (0.93-0.99). The bias and limits of agreement between HBS\textsubscript{1} and HBS\textsubscript{2} are shown in a Bland-Altman plot (-2.12 ± 12.22 kg; Figure 4).

***INSERT FIGURE 4 NEAR HERE***

DISCUSSION

While the back squat exercise is frequently prescribed in both athletic and clinical populations to develop lower body muscular strength in a functional movement pattern (13,16,28), individuals with anterior glenohumeral instability or restricted glenohumeral ROM may be unable to safely achieve sufficient arm positioning to support the bar with their hands (11). Therefore, the purpose of this study was to report on the validity of the HBS compared to a traditional back squat, and to determine its intersession reliability. The main findings of this paper demonstrated a very strong relationship between maximal levels of strength measured between the traditional back squat and HBS exercises, as well as high intersession reliability when using the HBS exercise to quantify 1RM. These data suggest that the HBS may be used as a valid alternative to the traditional back squat when quantifying lower body strength.

During the traditional back squat, the glenohumeral joint is maintained in a position of humeral abduction combined with external rotation to allow the hands to support the bar on the upper trapezius (5,11,14). Due to the large amount of muscle mass recruited to perform the back squat, 1RM scores for healthy males athletes can range between ~110-180 kg, with exceptional athletes often lifting up to 250 kg (14). These large loads in combination with an abducted and externally rotated shoulder
position result in extensive stress on the glenohumeral complex, and should therefore be avoided by those suffering anterior glenohumeral instability or restricted ROM in the shoulder (5,11,14). Indeed, these individuals may experience pain in posterior region of the shoulder when placing the upper extremities in this position (15). While the front squat has been proposed as an alternative exercise for these populations, it is estimated that during the initial learning phase individuals will only be able to lift ~60% of their back squat 1RM, which increases to ~80% after achieving technical proficiency in the exercise (14). Furthermore, individuals who are unfamiliar with the front squat often lack the required flexibility in the wrist and shoulder to maintain correct hand and arm placement when in the front rack position (2). Special populations (i.e. individuals with amputation) may also be unable to support the bar with the hands across the anterior deltoids and clavicles to perform the front squat.

As a consequence, individuals who are unable to train with the back squat, but require adaptations specific to this exercise (e.g. competitive power lifters recovering from shoulder injury), may have inadequate responses to training solely with the front squat. Furthermore, the application of the front squat is limited in individuals who are unable to support the bar in the front rack position with their hands. The HBS used in the current study allowed subjects to perform the back squat movement without requiring abduction and external rotation of the shoulder. Indeed, the shoulder position maintained during the HBS (i.e. neutral abduction combined with internal rotation) will likely place less stress on the inferior glenohumeral ligament (11), which acts as the primary static stabilizer of the glenohumeral joint in the abducted position (15,26). While subjects in the current study were not required to un-rack or re-rack the bar from its supportive peg during the HBS, this exercise may offer benefit for individuals training alone with single-sided limitations in ROM (i.e. post shoulder
surgery), who are able to maintain the restricted arm in a pain-free position whilst rotating the bar with their other hand. Maintaining at least one hand on the bar may also be advantageous for encouraging a position of scapular retraction, which will promote good contact between the rigid harness and the upper trapezius. Indeed, sufficient scapular retraction during back squat variations provides a “shelf” for bar positioning, and allows the upper back musculature to remain stable and erect during the squatting movement (22). However, as comparisons were made between the traditional back squat and the HBS exercises in the current study, subjects were required to be free of shoulder pathologies that could affect their ability to perform the back squat. Future research should therefore aim to assess the use of the HBS in subjects with restricted glenohumeral ROM, and the efficacy of training these populations with this apparatus.

To determine criterion validity, data are often compared against a gold standard to assess whether information provided by new equipment or techniques in fact measure what they are designed to (17). Previously, correlation analyses have been used to examine the validity of force and power data during squat and jumping exercises (8,10). As the current study observed no significant differences in 1RM scores between HBS\(_1\) and HBS\(_2\), the validity of the HBS to quantify 1RM was assessed via correlation analysis between the back squat and HBS\(_{\text{mean}}\). A very strong relationship (\(r = 0.96\)) was observed between 1RM scores on the back squat and HBS\(_{\text{mean}}\) (Figure 2). Furthermore, the amount of weight lifted in 1RM tests of the back squat did not differ from 1RM scores from HBS\(_1\), HBS\(_2\) or HBS\(_{\text{mean}}\). These findings are in agreement with previous research, which reported no significant differences between 1RM scores determined using the back squat exercise with free weights or in a Smith Machine in resistance trained young men (6). However, the
Bland-Altman plot demonstrates that stronger subjects (i.e. mean 1RM >160 kg) were more likely to demonstrate increased variability between the back squat and $HBS_{\text{mean}}$ 1RM scores (Figure 3). These findings may reflect that stronger subjects utilise their arms to a greater extent when stabilizing the bar during the traditional back squat exercise, which could account for their increased variability when performing the HBS without this support. Future research should consider whether stronger subjects do indeed employ their arms to a greater extent during the back squat exercise when compared to experienced, though markedly weaker subjects. Nonetheless, while the current data may reflect some level of disagreement between the back squat and $HBS_{\text{mean}}$ in stronger individuals, it is important to consider that the Bland-Altman analysis was performed using absolute values, and larger absolute variations from the bias would be expected for these subjects. The limits of agreement between 1RM scores in the back squat and $HBS_{\text{mean}}$ in the current study are also smaller than previously reported for test-retest analysis of 1RM for a Smith Machine back squat (27). Taken together, these data suggest that the HBS used in the current study is valid for quantifying maximum strength in the back squat exercise.

Reliable evaluations of muscle strength are important to prescribe safe and effective resistance training intensities, and to evaluate the efficacy of training (23). The present study observed a very strong ICC (0.98) between $HBS_1$ and $HBS_2$. This is similar to previous research which also reported a very strong ICC (0.94) for the reliability of 1RM testing using the Smith Machine back squat in subjects with at least two years resistance training experience (27). However, it has been suggested that ICC values may overestimate reliability, particularly when no other tests of reliability are examined (1). Therefore, typical error, which reflects the change in scores between tests (19), was also assessed. As recommended by Hopkins (19), typical error
was reported as CV as this allows direct comparisons between different studies, and facilitates simple interpretation of the reliability of measurements across various scales and measurements. Results of the current investigation demonstrated a CV of 2.6% (1.9-4.3) between HBS_1 and HBS_2. This is similar to results previously reported by Levinger et al. (23), who established that the CV of 1RM assessment across seven different resistance exercises ranged between 2.2-10.1%. These data collectively suggest that the HBS used in the current study is reliable for assessing 1RM.

The current data demonstrate that in subjects with prior resistance training experience, 1RM scores for the HBS were not significantly different across two testing sessions. This suggests that there was no learning effect or changes in strength and/or motivation between testing sessions that affected 1RM performance. However, the Bland-Altman plot comparing HBS_1 and HBS_2 demonstrates a tendency for subjects with lower mean 1RM scores (i.e. 1RM <130 kg) to perform best during HBS_2, whereas stronger subjects (i.e. 1RM >160 kg) performed best during HBS_1 (Figure 4). While most data points lay within the limits of agreement, these findings agree with Ritti-Dias et al. (27), who proposed that subjects with prior resistance training experience have a largely heterogeneous response between 1RM testing sessions. Therefore, differences in 1RM scores both above and below the mean between-session difference would be expected.

Previous research has determined that individuals with prior resistance training experience do not require extensive familiarization prior to determining 1RM for the Smith Machine back squat, and do not demonstrate strength increases between testing sessions (27). As such, only one session should be required to accurately assess 1RM in these populations (27). This is also highlighted by the current study, as no significant change in 1RM scores between HBS_1 and HBS_2 was observed.
Therefore, these data confirm that in experienced cohorts, only one testing is necessary to quantify 1RM using the HBS, providing subjects have been familiarized with the exercise.

It is important to note that the current study did not extend to a kinematic or kinetic analysis of joint movements during the HBS. Therefore, while performance in 1RM testing was similar between the back squat and HBS, it is possible that differences exist in both lower- and upper-body joint forces and muscle activation between the two exercise variations. Indeed, previous research has identified that the traditional back squat elicits a 43% higher average muscle activation of the trunk and legs than the Smith Machine back squat (29). Future research should compare kinematic and kinetic data, as well as any the degree of muscle activation, between the traditional back squat and the HBS.

In conclusion, the current data demonstrate that the HBS exercise provides a valid and reliable measure lower body of maximum strength, when compared to the traditional back squat. As the HBS does not require sustained humeral abduction and external rotation to support the bar during the squatting action, this exercise may provide a viable alternative for individuals in which this glenohumeral position may be contraindicated or unachievable. Furthermore, as no significant differences and high measures of reliability were observed between 1RM scores in HBS₁ and HBS₂, the results of this study confirm that a single testing session is sufficient to obtain reliable 1RM scores in cohorts with at least two years previous resistance training experience.
PRACTICAL APPLICATIONS

The results of the current study provide beneficial information for strength and conditioning coaches seeking an alternative to the traditional back squat for individuals with glenohumeral instability or restricted ROM. These findings indicate that 1RM testing using the HBS is both valid and reliable for young men with at least two years resistance training experience. This is of particular importance for individuals recovering from shoulder surgery where humeral abduction and external rotation may be contraindicated. As no differences were found in 1RM between the two squat variations, these individuals would be able to train under similar loads using the HBS as they would with a traditional back squat. Furthermore, the HBS may be useful for exercise and sport scientists in a research context, as it may allow for indwelling bodies (i.e. an intravenous cannula) to be present in the hand or arm during resistance exercise, without the risk of damage to surrounding tissue caused by gripping a bar. Data from the current study also confirms that individuals with at least two years prior resistance training experience do not require more than one testing session to quantify 1RM. Therefore, the use of 1RM tests to assign training loads or evaluate the efficacy of training programs can be implemented easily, particularly for recreational resistance training, as several 1RM testing sessions are not necessary for this cohort.

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REFERENCES


FIGURE LEGENDS

**Figure 1.** The customized rigid supportive harness from (a) an anterior view, (b) a posterior view and (c) during the Smith Machine HBS exercise.

HBS = harness back squat.

**Figure 2.** Pearson’s product moment correlation between 1RM scores with the back squat exercise and mean 1RM scores with the modified Smith Machine HBS exercise.

1RM = 1-repetition maximum; HBS = harness back squat.

**Figure 3.** Bland-Altman plot of 1RM scores for each participant measured using the back squat and HBS (mean of two testing sessions) exercises. Thick solid line represents the bias between the two tests, and dashed lines represent the limits of agreement (± 1.96 SD).

1RM = 1-repetition maximum; HBS = harness back squat.

**Figure 4.** Bland-Altman plot of HBS 1RM scores for each participant during two testing sessions. Thick solid line represents the bias between the two tests, and dashed lines represent the limits of agreement (± 1.96 SD).

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