Simple anthropometric and physical performance tests to predict maximal box-lifting ability

Running head: Predicting box-lift ability

ALUN G. WILLIAMS†* and MICK WILKINSON‡

†Institute for Biophysical and Clinical Research into Human Movement, Manchester Metropolitan University.

‡Division of Sport Sciences, University of Northumbria at Newcastle.

*Corresponding author:

Alun Williams PhD
Institute for Biophysical and Clinical Research into Human Movement
Manchester Metropolitan University
Hassall Road
Alsager
UK
ST7 2HL

Email: a.g.williams@mmu.ac.uk

Tel: +44 (0)161 247 5523
Fax: +44 (0)161 247 6375

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ABSTRACT

Box-lifting ability is an important characteristic of military personnel. The purpose of this paper was to determine the usefulness of the upright row free weight exercise, and simple anthropometric tests, to predict maximal box-lifting performance that simulates the loading of military supply vehicles. Two groups of adults performed maximal box lifts to 1.4 m (study one) and 1.7 m (study two) respectively. All subjects were also tested for upright row 1-repetition maximum (1RM) strength, body mass, height and body composition. In study one, a remarkably good prediction of maximal box-lift performance to 1.4 m (42 ± 12 kg) was obtained from a regression equation including the variables body mass, body composition and upright row 1RM. Approximately 95% of the variation in 1.4 m box-lifting performance could be accounted for. In contrast, in study two, only 80% of the variation in 1.7 m box-lifting performance (51 ± 15 kg) could be accounted for by the best predictor equation. Upright row 1RM strength appears to be a useful tool in the prediction of box-lifting ability to approximately chest height for most adults, probably due to a close match between the muscle groups and contraction modes required during both tasks. Military or other organizations could use the data reported here to substitute simple anthropometry and a 1RM test of strength and for the direct assessment of 1.4 m box-lifting performance.

***Keywords**:* Muscle strength; Body composition; Manual handling

INTRODUCTION

Box lifting is a task required in many occupations, especially those where mechanical options are prohibitively expensive or not feasible on practical grounds. In military occupations where the movement of boxes and other heavy, awkward materials may be required at any time and in any environment, sufficient human muscle strength must be available to achieve the task. Thus, maximal box-lifting ability is important in a military context (19).

In the British Army, two maximal lifts have been identified as representative of the tasks that soldiers may routinely be required to complete - these box lifts are to the heights of 1.45 m and 1.70 m (19). These heights actually correspond to the heights of two military vehicles, but also approximate the heights of lifts that soldiers may need to perform in other activities (19). Subsequent to this research (17, 19), the heights of 1.45 m and 1.70 m have been adopted by the British Army as standard heights during the assessment of box-lifting ability, and adequate performance on these tests has implications for both the operational effectiveness and career progression of many thousands of soldiers. However, issues of safety, skill requirements and logistics during the assessment of maximal box-lifting ability mean that simple anthropometric tests or relatively unskilled physical performance tests may be useful substitutes for these box-lifting tasks (17). In particular, the strain placed on the lower back musculature during maximal box lifting may make assessment of maximal box-lifting ability a potential cause of injury.

Several previous studies have already investigated the ability of relatively simple anthropometric or physical performance tests to predict maximal box lift ability. Some of these studies have used heights of lift considerably lower than the 1.45-1.70 m of primary relevance to the British Army (3, 16), and are therefore likely to require the recruitment of different muscle groups. Some other studies have used lift heights comparable with the 1.45-1.70 m of primary interest to the British Army, but have limited the mass lifted to 72 kg which affected the performance score of a significant proportion of subjects (17, 18) or have been focussed on repetitive lifting capacity (2, 7). The studies providing data most relevant to maximal box-lifting ability to 1.45-1.70 m have suggested that simple anthropometric measurements including stature, fat-free mass and chest circumference (12, 13, 15, 17, 18), isometric back extension or lifting strength (12, 15, 17, 18, 20, 21) and dynamic strength assessed using an incremental lift machine (13, 15, 17, 18, 20, 21) are probably the most useful predictors of task performance. However, it would also be useful to determine the ability of a safe, easily controlled free weight exercise (requiring only widely available apparatus) to predict box-lifting ability.

Consequently, the aim of this study was to examine the usefulness of simple anthropometric tests and a field-based method of strength assessment that requires only free weights for the prediction of performance on box-lifting tasks, which simulate the loading of military supply vehicles.

METHOD

Approach to the Problem

Two studies were conducted. The aims of studies one and two were to evaluate the potential for anthropometric tests and a free weight strength test to predict the ability to perform a box-lift to heights of 1.4 m and 1.7 m respectively (approximating the heights of two military supply vehicles).

Subjects

A total of 29 healthy, physically active young adults served as subjects (10 women, 19 men) in the two studies. Both studies received ethical approval from the Ethics Committee at the College of Ripon and York St. John, UK. All subjects passed routine medical screening and provided written informed consent.

Procedures

All 29 subjects were assessed for stature (stadiometer with horizontal headboard) and body mass (levelled platform scale) while wearing gym shorts and T-shirt using calibrated equipment and standard laboratory procedures (4). Body composition was assessed by a single experienced assessor using Harpenden calipers (Holtain Ltd., Crymych, Pembrokeshire, UK) and the sex-specific three site methods of Jackson and Pollock (5, 6). Each skinfold was measured in triplicate, and the mean at each site used in analysis. The intra-class test-retest correlation coefficient for skinfold measurements was R = 0.99, and ratio limits of agreement (14) were 1.00 */÷ 1.09. Fat-free mass (FFM) was calculated using the body mass and percentage body fat (% fat) data. Following a standardized warm-up and familiarization, 1RM strength was determined on a barbell upright row task (Figure 1). The upright row requires the movement of a weighted bar from waist height (full arm extension) to shoulder height, keeping the bar close to the trunk, using a narrow overgrasp handgrip and with stationary legs and trunk (11). The major muscle groups recruited during the upright row are the bicep group for elbow flexion and deltoid group for shoulder frontal plane abduction. The assessment of 1RM using a standard protocol (9) initially involved conducting a light warm-up of 5-10 repetitions at 40-60% of perceived maximum. After a 1-min rest with light stretching, 3-5 repetitions at 60-80% perceived maximum were completed. A conservative increase in mass was then made, and a 1-RM lift attempted. If the lift was successful, a rest period of 3-5 min was allowed, and then a further attempt allowed. This process continued until a failed attempt occurred. The 1-RM was recorded as the mass of the last successful lift. The intra-class test-retest correlation coefficient for upright row 1-RM was R = 0.99, and ratio limits of agreement were 1.01 */÷ 1.13.

In study one, seven days after the anthropometric and upright row 1RM tests, 14 subjects (7 men (mean ± SD age 20 ± 1 years, stature 1.78 ± 0.06 m, body mass 81.1 ± 8.4 kg) and 7 women (age 20 ± 0 years, stature 1.65 ± 0.05 m, body mass 64.4 ± 7.3 kg)) also completed a 1RM test of box-lifting ability involving the movement of a plastic box (dimensions 0.7 m x 0.5 m x 0.3 m) with handles on each side from floor level onto a platform 1.4 m in height. Subjects were advised on lifting techniques, but essentially the lift was freestyle as long as safety was not compromised. In particular, the test was terminated if there was extreme hyperextension of the lower back, or if exaggerated twisting occurred during the lift. Subjects rested for 3-5 min between lifts while two safety spotters returned the box to the floor. The intra-class test-retest correlation coefficient for 1.4 m box-lift 1-RM was R = 0.97, and ratio limits of agreement were 1.00 */÷ 1.09.

In study two, seven days after the anthropometric and upright row 1RM tests, 15 subjects (12 men (age 22 ± 5 years, stature 1.79 ± 0.06 m, body mass 79.0 ± 11.5 kg) and 3 women (age 25 ± 9 years, stature 1.62 ± 0.10 m, body mass 63.0 ± 11.1 kg) also completed a 1RM test of box-lifting ability involving the movement of the plastic box from floor level onto a platform 1.7 m in height. Again, subjects were advised on lifting techniques, but essentially the lift was freestyle as long as safety was not compromised. The intra-class test-retest correlation coefficient for 1.7 m box-lift 1-RM was R = 0.99, and ratio limits of agreement were 1.01 */÷ 1.10.

Statistical Analyses

All data were analyzed using the SPSS for Windows (Release 11.5.0) statistical software package (SPSS Inc., Chicago, IL). The ability of the variables age, sex, stature, body mass, % fat, FFM and 1-RM upright row to predict box-lifting ability were analyzed using backwards elimination linear regression. The R value, the adjusted R^2 value (R^2 Adj) and the standard error of the estimate (SEE) obtained via SPSS were reported. The adjusted R^2 value is calculated using the formula $1 - ((1-R^2)(N - 1 / N - k - 1))$ and is the key statistic reported here as the number of independent variables relative to the sample size is corrected for, thus yielding a more honest value to estimate the R^2 for the wider population. Thus, the danger of calculating artificially inflated coefficients of determination is avoided. Furthermore, the predicted data shown in Tables and Figures are adjusted predicted values – i.e. those produced when the case itself is removed from the calculation of the regression coefficients. Importantly, therefore, the ability of SPSS to produce adjusted coefficients of determination and adjusted predicted data values both provides realistic R^2 magnitudes and eliminates the need for a second, independent sample of subjects on which to validate the regression models. The accepted level of significance was set at $P = 0.05$ for all analyses. Data are expressed as mean ± SD.

RESULTS

The data for box lift, predicted box lift, upright row, FFM and % fat from studies one and two are shown in Tables 1 and 2, respectively.

In study one, a significant prediction of 1.4 m box-lift from a model containing body mass, % fat, upright row and FFM was achieved (R = 0.984, R^2 Adj = 0.954, P<0.0005, SEE = 2.5 kg; Figure 2). Similar analyses for men and women separately produced models containing body mass (R = 0.847, R^2 Adj = 0.660, P=0.016, SEE = 1.9 kg) and upright row (R = 0.850, R^2 Adj = 0.667, P=0.015, SEE = 2.9 kg), respectively. The regression model to predict maximal 1.4 m box lift derived from the whole group of 14 subjects is shown in Equation 1 that follows:

Predicted Box Lift = 63.513 + (3.395·Mass) + (1.049·Upright Row 1RM) – (4.359·FFM) – (2.839·% fat) (1)

In study two, a significant prediction of 1.7 m box-lift from a model containing age, sex, stature and % fat was achieved (R = 0.926, R^2 Adj = 0.801, P<0.0005, SEE = 6.9 kg; Figure 3). A similar analysis for men separately produced a model containing only body mass (R = 0.695, R^2 Adj = 0.431, P=0.012, SEE = 9.1 kg). There were insufficient subjects in study two for an analysis for women only.

DISCUSSION

The main finding from study one is that a remarkably good prediction of box-lifting ability to a height of 1.4 m can be obtained from a combination of simple anthropometric and performance measurements. Approximately 95% of the variation in 1.4 m box-lifting ability can be explained by the simple tests adopted, and this value exceeds those reported in previous studies on this topic (12, 13, 15, 17, 18, 20, 21). The 2.5 kg SEE value is also good, in the context of maximal lifts in the region of 30-50 kg. The regression model reported here includes only simple anthropometric measurements (body mass, percentage body fat, fat-free mass) and a field-based strength test that requires only free weights (upright row). Therefore, a good prediction of 1.4 m box-lifting ability can be obtained from tests that require only a short period of time to conduct, minimal expertise and widely available apparatus.

One aspect of study one that is different to any previous research is the performance test used. The use of free weights in the upright row exercise appears to be a useful test of the relevant upper body musculature (predominantly the bicep and deltoid muscle groups) in a relevant movement pattern. Although the muscles of the legs and lower back are important for a lift from floor to waist height (8), the limiting stage of a higher box lift to 1.4 m is likely to be the second phase of movement – from waist height to platform height. In this second phase of movement, the strength of the bicep and deltoid muscle groups is more likely to be the limiting factor to performance than leg strength and lower back strength, which are likely to be acting only as fixators during this phase of the lift. Indeed, the Pearson correlation directly between 1.4 m box-lifting performance and upright row performance was itself extremely high (r = 0.958), and higher than that between box-lifting performance and any other variable measured. Furthermore, Table 1 shows the data for 1.4 m box-lift and upright row 1RM are remarkably similar – not only are these two measurements highly correlated, but the actual masses lifted are virtually identical. It appears that the upright row 1RM test using free weights is extremely applicable to the prediction of 1.4 m box-lifting performance. Also of note is the fact that the upright row test is probably a relatively safe test to conduct, even with untrained subjects. This statement is based on the fact that during the upright row the weight bar is kept close to the trunk and the trunk remains stationary - and therefore does not require maximal recruitment of the lower back musculature.

The coefficients of determination obtained for box-lifting to 1.4 m for men and women as separate groups were reduced from 95% obtained for the combined group to values of approximately 66% due to the more limited range of the observed data (1). Nevertheless, the SEE values remained at approximately 2-3 kg and upright row 1RM strength remained the most powerful predictor variable for the women group, although body mass was the single variable included in the regression model for men.

The main finding from study two is that a very good prediction of box-lifting ability to a height of 1.7 m cannot be obtained from the combination of simple anthropometric and performance measurements used here. Approximately 80% of the variation in 1.7 m box-lifting ability can be explained by the simple tests adopted, and this value is notably lower than that obtained for the prediction of box-lift to the lower 1.4 m height. Furthermore, the SEE (~7 kg) was greater than for the 1.4 m height. Box-lifting to 1.7 m involves use of not only the bicep and deltoid muscle groups, but also a greater reliance on other muscle groups including the triceps group (compared to the 1.4 m lift) for even subjects as tall as the tallest subject in study two (stature 1.86 m). Therefore, the reduced ability of the upright row 1RM strength test to predict 1.7 m box-lifting performance may be due to the fact that the muscle groups involved in the limiting phase of the box lift – probably the final push of the box from approximately shoulder height to platform height – are not assessed using the upright row. Indeed, the regression model produced included age, sex, stature and % fat as predictor variables. Upright row 1RM strength is conspicuous by its absence, given the impressive results for the 1.4 m lift. Perhaps a different strength test using free weights could be chosen/designed that better simulates the lifting of a heavy load to a height above shoulder level. A shoulder press - involving shoulder frontal plane abduction and elbow extension, requiring the recruitment of upper back, deltoid and triceps muscle groups (11) - may be a good starting point for such future research. However, an original strength test may have to be designed, as the full arm extension normally achieved in a shoulder press is not likely to occur in most box lifting tasks for most individuals.

In conclusion, a useful predictive equation for 1.4 m box-lifting has been produced using simple anthropometric measurements and a test of upright row 1RM strength. This equation has potential applications for organizations that routinely conduct tests of box-lifting ability, and particular application in the British Army where the height approximates that of a commonly used military supply vehicle. Of course, different military organizations should consider their own common tasks (e.g. the heights of commonly used vehicles) to evaluate the applicability of these findings to their specific environment. It is suggested that the inability of the upright row to assist in predicting box lifting performance to 1.7 m (the height of another British Army military supply vehicle) is due to relatively poor replication of the box lifting movement to this height by the upright rowing task. However, no established tests of muscle strength currently exist that simulate such a high lift satisfactorily. Future studies should utilize a strength testing task that is more specific to the movements involved in box lifting to a platform 1.7 m high. It is also worth noting that the sample sizes used in this research were rather lower than some previous work, and future studies would ideally include greater numbers of subjects than the current paper to increase confidence in the results. Finally, future research should also explore the ability of predictive independent variables to track training-induced changes in box-lifting performance (25), given the central and important role of physical training programs (10, 22-24) in military organizations.

PRACTICAL APPLICATIONS

The British Army (and possibly other organizations) could use the data reported here to substitute simple field-based tests of strength and anthropometry for the direct assessment of 1.4 m box-lifting performance. This would probably reduce the risk of injury during testing, as a box-lift using a large container would be replaced with simple anthropometric tests and a free-weight exercise that is more easily conducted with a controlled technique. The equipment required to conduct the upright row test is already located in the gymnasia of many military establishments, so there would probably be minimal logistical problems with such an approach. In fact, the need to create an artificial 1.4 m platform or use a military vehicle of a suitable size would be eliminated.

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Table 1. Performance and body composition data in study one.

	All subjects (n = 14)	Men (n = 7)	Women (n = 7)
1.4 m box lift (kg)	42 ± 12	53 ± 3	32 ± 5
Predicted 1.4 m box lift (kg)	42 ± 11	53 ± 3	32 ± 4
Upright row (kg)	42 ± 13	54 ± 4	30 ± 4
FFM (kg)	59 ± 13	70 ± 3	47 ± 7
Body fat (%)	20 ± 9	13 ± 7	26 ± 4

Table 2. Performance and body composition data in study two.

	All subjects (n = 15)	Men (n = 12)	Women (n = 3)
1.7 m box lift (kg)	51 ± 15	56 ± 12	29 ± 4
Predicted 1.7 m box lift (kg)	51 ± 14	56 ± 8	Insufficient data
Upright row (kg)	47 ± 13	52 ± 9	27 ± 3
FFM (kg)	64 ± 12	69 ± 8	46 ± 7
Body fat (%)	15 ± 9	12 ± 6	27 ± 6

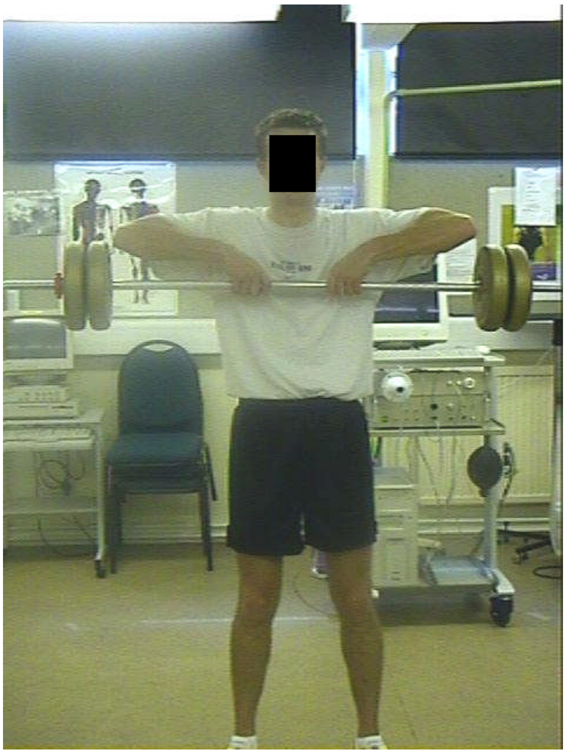

Figure 1. A subject performing the upright row test.

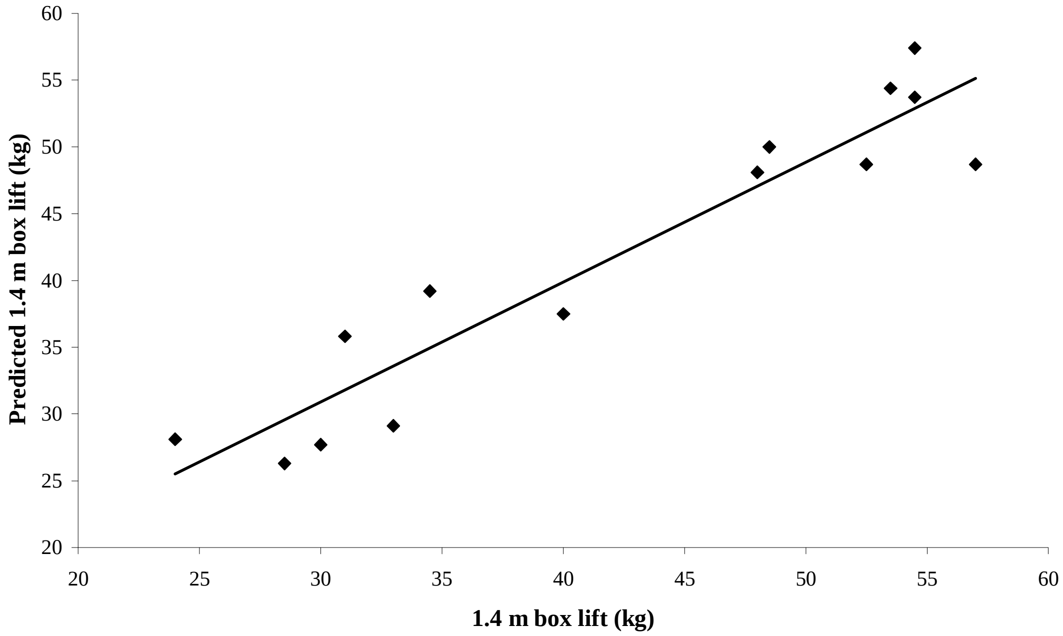

Figure 2. Relation between actual and predicted 1.4 m box lift. The prediction model contains body mass, % fat, upright row and FFM (R^2 Adj = 0.954, P<0.0005, SEE = 2.5 kg).

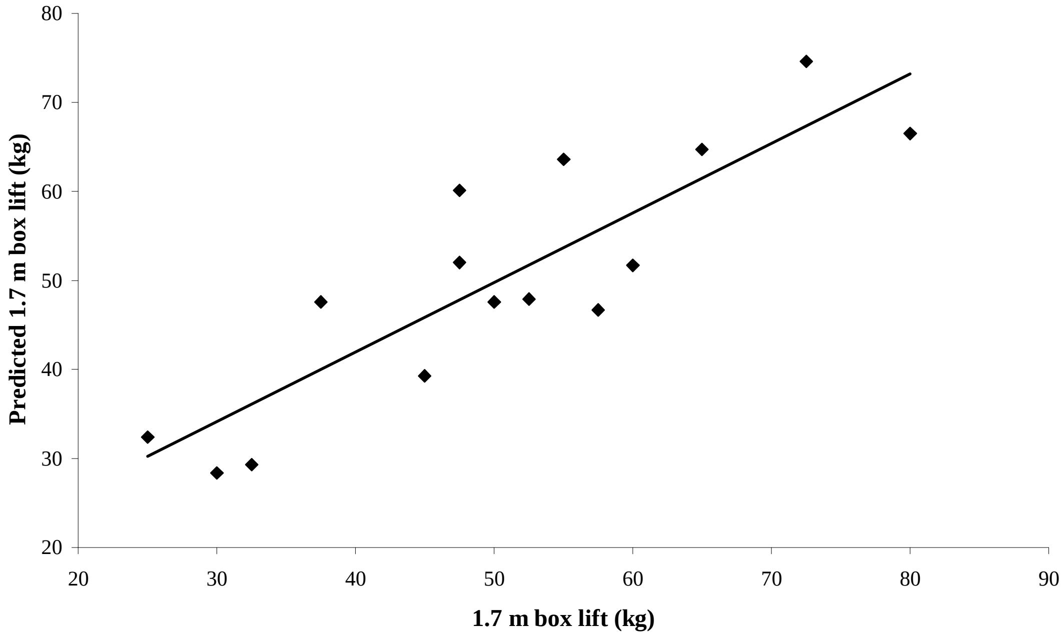

Figure 3. Relation between actual and predicted 1.7 m box lift. The prediction model contains age, sex, stature and % fat (R^2 Adj = 0.801, P<0.0005, SEE = 6.9 kg).