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Published in:
Journal of Strength and Conditioning Research

DOI (link to publication from Publisher):
10.1519/JSC.0000000000004347

Publication date:
2023

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Kristiansen, M. V., Pedersen, A.-M. S. K., Sandvej, G., Jørgensen, P., Venneberg Jakobsen, J., de Zee, M., Hansen, E. A., & Klitgaard, K. K. (2023). Enhanced Maximal Upper-Body Strength Increases Performance in Sprint Kayaking. *Journal of Strength and Conditioning Research*, *37*(4), e305-e312. https://doi.org/10.1519/JSC.0000000000004347

the Journal of Strength and Conditioning Research™

Enhanced Maximal Upper-Body Strength Increases Performance in Sprint Kayaking

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Abstract

Kristiansen, M, Sydow Krogh Pedersen, A-M, Sandvej, G, Jørgensen, P, Jakobsen, JV, de Zee, M, Hansen, EA, and Klitgaard, KK. Enhanced maximal upper-body strength increases performance in sprint kayaking. *J Strength Cond Res* XX(X): 000–000, 2022—The association between upper-body strength and performance in 200-m flat-water sprint kayak is not fully elucidated. Therefore, the aim of study 1 was to investigate the relationship between upper-body strength and kayaking performance. In study 2, the aim was to perform a randomized training intervention to investigate whether a causal relationship was present between an increase in strength and an actual change in 200-m kayaking performance. In study 1, 37 (22 men and 15 women) elite kayak paddlers performed tests of maximal power output, isometric force, 1 repetition maximum (1RM), and 40 seconds of maximal repetition number in bench press and bench pull and a 30-second all-out on-water sprint kayak test. In study 2, 26 (16 men and 10 women) national elite junior A, U23, and senior kayak paddlers were allocated into 2 groups: a training group (TRAIN) and a maintenance group (MAIN). Each group completed a 6-week strength training intervention with the purpose of either increasing 1RM in bench press (TRAIN) or maintaining strength (MAIN). Pre- and posttests were performed in 200-m kayak ergometer sprint, 1RM bench press, and 1RM bench pull. In study 1, 1RM in bench press was the best predictor of 30-second on-water kayaking performance with a regression coefficient of 0.474. In study 2, TRAIN significantly increased 1RM strength in bench press (pre: 87.3 ± 21.2 kg, post: 93.9 ± 21.3 kg, $p = 0.001$) and bench pull (pre: 84.2 ± 15.3 kg, post: 86.0 ± 15.1 kg, $p = 0.025$). In the 200-m kayak ergometer sprint test, TRAIN significantly decreased the time to complete the test (pre: 44.8 ± 4.3 seconds, post: 44.3 ± 4.3 seconds, $p = 0.042$). In bench press, 1RM was the best predictor of 200-m kayaking, and an increase in bench press 1RM resulted in increased kayaking performance.

Key Words: force production, sprint canoeing, performance prediction, resistance training, strength and conditioning, sprint performance

Introduction

Flat-water sprint kayaking is a competitive sport that has been part of the summer Olympic games since 1936. Competitors typically compete over 200, 500, or 1000 m. The various distances create the need for individualized training approaches as the contribution from different energy systems varies considerably between distances. For instance, in the 200-m distance, the contribution from the aerobic and anaerobic energy systems has been shown to amount to 37 and 63%, respectively (4). For the 1000-m distance, the aerobic and anaerobic contributions amount to 82 and 18%, respectively (4).

The contribution of the anaerobic energy system increases as the race distance shortens, thus creating a greater demand for generating anaerobic power. Because anaerobic power in kayaking can be expressed as maximal power output per stroke, it is inherently limited by muscle strength, more specifically upper-body strength. As a result, strength training of the upper-body plays an integral role in optimizing performance outcomes during sprint kayaking (7). The focus of the current study is on the 200-m race because the anaerobic contribution is highest during this discipline, and therefore, strength training will most likely have the highest effect on performance.

Several studies have shown strong negative correlations between upper-body strength and 200-m kayak sprint time. For instance, Picket et al. found a strong negative relationship between 3 repetition maximum (RM) in bench press and bench pull exercises and 200-m race time ($r = -0.80$ and -0.76, respectively) (15). In addition, a moderately negative relationship between dynamic strength, measured on a dynamometer positioned to simulate a paddle stroke, and 200-m kayak sprint time has previously been reported ($r = -0.57$; $p = 0.013$) (17). Moreover, McKean and Burkett followed a group of elite sprint kayakers over a period of 3 seasons and found significant correlations between increases in 1RM bench press strength and decreases in the time to kayak 1000, 500, or 200 m (13).

Although an important relationship seems to exist between measures of upper-body strength in the bench pull and bench press exercises, this relationship is not fully elucidated. First, several strength tests have been used in the literature and are currently being used in practical sport settings, including 1RM, 3RM, isometric, isokinetic, and maximal repetition tests at submaximal intensities. The specific associations between these different measures of strength and kayak sprint performance are currently not clear, although biomechanical models have been developed in this regard (8). Second, the fact that upper-body

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strength negatively correlates with kayak sprint time does not prove a causal relationship between the two. This causal relationship between upper-body strength and sprint performance has only sparsely been investigated because very few studies have sought to directly assess the effects of strength training interventions on kayaking performance. Recently, Gäbler et al. (6) investigated the effects of either low-intensity high-volume or moderate-intensity low-volume strength training for 1 season on kayaking performance in 13-year-old adolescent boys and girls. However, they did not find any improvements in a 250-m kayak time trial, handgrip force, or muscular power test. Lum et al. conducted a 6-week training intervention to investigate isometric strength training versus traditional strength training in relation to 200-m kayak ergometer performance (12). Although both groups showed significant improvements in strength levels and 200-m kayaking performance, the isometric group displayed greater performance gains. Finally, Liow and Hopkins investigated the effect of slow and explosive strength training in bench press and prone dumbbell pull in a 15-m kayak sprint performance test (11). Both training groups showed significant improvements in 1RM strength, although the slow strength training group had a greater improvement in 15-m sprint time (3.4 ± 1.3%) than the explosive strength training group. To the best of our knowledge, no other studies have investigated the effect of deliberately enhancing upper-body maximal dynamic strength on the associated kayak sprinting performance.

Therefore, the aim of the current investigation was twofold and thus divided in to 2 studies. In study 1, the aim was to investigate the relationship of different strength test outcomes (maximal power output, isometric force, 1RM, and 40-second maximal repetition number) of bench press and bench pull in relation to 200-m flat-water kayak sprint performance. In study 2, the aim was to investigate whether a causal relationship was present between the strength test outcome showing the greatest association with kayak sprint performance (from study 1) and 200-m kayak sprinting performance. For this purpose, a training intervention was conducted. We hypothesized that maximal dynamic upper-body strength (1RM) would show the highest correlation with kayaking performance and that improvement of this variable through training would also bring about performance improvements in 200-m kayak sprinting performance.

Methods

Experimental Approach to the Problem

A cross-sectional study design was used to test the hypothesis in study 1. The subjects were tested on 3 consecutive days. On day 1, two 30-second on-water sprint tests were conducted. On day 2, isometric strength testing in the bench pull and bench press exercise was performed. On day 3, maximal power output, 1RM, and maximal repetitions performed within 40 seconds were tested in the bench pull and bench press exercises.

To test the hypothesis in study 2, a randomized training intervention was performed. The subjects were divided into 2 groups, a training group (TRAIN) and a maintenance group (MAIN). To establish as homogeneous groups as possible, the groups were randomized and stratified in relation to regional kayak club, sex, and 1RM in bench press. The purpose of TRAIN was to increase 1RM in bench press and maintain strength in the other exercises, whereas the purpose of MAIN was to maintain the strength in all exercises performed. This intervention investigated the differences in 200-m kayak sprint performance in a group with an increased maximal bench press strength compared with a similar group with no increase in maximal bench press strength. Both groups followed their normal kayak training routine in addition to the strength training intervention. The subjects were tested in 200-m ergometer kayak sprint, 1RM bench press, and 1RM bench pull before and after 6 weeks of strength training. All tests were conducted on the same day in the same order for each subject at both pre- and posttesting.

Subjects

In study 1, 37 elite kayak paddlers (22 men: age 17.5 ± 1.8 years (mean ± SD), body mass 75.6 ± 10.7 kg, height 181.5 ± 8.1 cm, and 15 women: 17.2 ± 1.4 years, 63.7 ± 7.1 kg, 170.7 ± 5.4 cm) from 2 regional kayak centres (Talentcenter Hovedstaden and Super Kraftcenter Silkeborg) participated. In study 2, 26 national elite junior A, U23, and senior kayak paddlers (16 men: age 18.6 ± 4.1 years, body mass 79.1 ± 7.8 kg, height 179.0 ± 5.1 cm, and 10 women: age 17.0 ± 1.4 years, body mass 64.9 ± 4.6 kg, height 168.5 ± 6.6 cm) from 3 regional kayak centres (Talentcenter Hovedstaden, Super Kraftcenter Silkeborg, and Kano og Kajakklubben Limfjorden) participated. The number of subjects to be included in study 2 was computed using an α level of 0.05, a β level of 0.20, and an effect size of 0.7 based on the results of Lum et al. (12). All subjects had at least 1 year of experience with free weight strength training and were informed about the procedures of the study both verbally and in writing before providing written informed consent. Parental or guardian consent was required for subjects under 18 years of age. The study was approved by the North Denmark Region Committee on Health Research Ethics and conformed to the standards set by the Declaration of Helsinki.

Procedures

In study 1, kayak sprint performance was assessed using a 30-second on-water kayak sprint test. This test resembles the duration of a 200-m race time at an international event (~35 seconds for men and ~40 seconds for women). The performance output was distance (in meters) measured using a GPS-based accelerometer (Minimax V4, Catapult, Australia, 2006), which has previously been validated for accuracy (5). The subjects' personal kayak and paddle were used for all sprint trials. The subjects underwent a standardized 15-minute warm-up with moderate-to-high intensities followed by 5 minutes of active rest before the first sprint trial. The subjects performed 2 trials and were instructed to paddle all-out on the trials. Fifteen minutes of active rest was imposed between the two 30-second trials. Immediately before all sprint trials, wind directions in relation to the sprint direction and wind velocity (in meters per second) were measured using an anemometer (VAV-1W—Mjölnir 2–24 $m \cdot s^{-1}$, Vaavud, Denmark, 2012–2018). Intraclass correlation coefficient (ICC) and coefficient of variation (CV) test-retest reliability measures were 0.97 and 0.10, respectively.

Because data collection was taking place during the winter season, the kayak sprint performance was assessed using a kayak ergometer in study 2. The kayak ergometer has previously been shown to replicate the physiological demands of on-water kayaking (16). The 200-m kayak ergometer all-out sprint test was conducted on a Dansprint kayak ergometer (Dansprint PRO kayak ergometer; Dansprint ApS, Hvidovre, Denmark). Drag resistance was regulated in relation to sex and age of the subject, and the same drag resistance was used at both the pre- and posttest. The subjects were instructed to paddle all-out from the start. A computer was connected to the ergometer, and time to completion was recorded with a Dansprint analyser (Dansprint analyser V.161; Dansprint ApS). The same test was performed before and after the 6-week training intervention. The same warm-up, as in study 1, was performed before ergometer testing. ICC and CV test-retest reliability measures were 0.99 and 0.10, respectively.

Strength Testing

In study 1, the strength testing consisted of testing isometric force output, maximal power output, 1RM, and maximal repetitions performed within 40 seconds in both the bench pull and the bench press exercises.

The test setup for isometric bench pull consisted of a custom-made pull bench placed on an AMTI force plate (AMTI force plate ACP; Advanced Mechanical Technology, Inc., Watertown, MA). The barbell was locked to an adjustable rack, which was mounted to the floor. When the subjects initiated the bench pull, the force was transferred to the force plate, and thereby, the maximal force was measured in the vertical direction. The grip was standardized to 110% of the biacromial width, and the barbell was placed below the caput ulnae and directly beneath the centre of rotation of the shoulders. The subjects used straps during the maximal pulls to minimize limitations from grip strengths and were told to keep the forehead on the bench throughout each trial. ICC and CV test-retest reliability measures were 0.99 and 0.20, respectively. For the bench press tests, the subjects were lying on an AMTI force plate to measure the maximal force in the vertical direction. The barbell was locked to an adjustable rack, and the press force was transferred directly to the force plate. The distance between the grip was standardized to 160% of the biacromial width. The distance between the force plate and the barbell was standardized to 85% of the individual's arm length, measured from acromion to caput ulnae. The subjects were positioned in the middle of the force plate relative to the rack with a 90-degree angle in the hip and knee joints to avoid contact between the feet and the force plate. ICC and CV test-retest reliability measures were 0.99 and 0.28, respectively. A warm-up was performed before the maximal isometric testing consisting of 10 repetitions with 40% of the subjects' self-estimated maximum followed by a 1-minute rest. Then, for familiarization purposes, 3 submaximal bench pulls or presses were performed with a duration of 4 seconds at 70, 80, and 90% of the subjects' self-estimated maximum. Again, each trial was separated by a 1-minute rest. Then, the subjects performed 3 maximal bench pulls or presses of a 4-second duration separated by a 2-minute rest. If the subjects reached the highest peak force in trial number 3, more trials were conducted until no further increase in peak force was observed.

A prone pull bench and a barbell were used to test the maximal power output in the bench pull exercise. The height of the bench was adjusted for the subject to grab the barbell with fully extended elbows while the barbell rested on the ground. The pull was accepted when the barbell touched the underside of the pull bench and the forehead was held on the bench. ICC and CV test-retest reliability measures were 0.99 and 0.31, respectively. A bench press rack and barbell were used to test the maximal power output in the bench press exercise. The barbell was lowered to the chest, and without bouncing, it was pressed up in fully extended arms. The press was accepted when the buttocks were kept on the bench throughout the pressing motion and the feet had contact with the floor. In both exercises, the subjects performed 3 single repetitions in each exercise separated by a 2-minute rest. The subjects were instructed to lift 50% of the self-estimated 1RM as fast as possible. If the subjects reached the highest peak power in trial number 3, more trials were conducted until no further increase in peak power was observed. ICC and CV test-retest reliability measures were 0.98 and 0.33, respectively. Before the maximal power output tests, a warm-up was performed consisting of 10 repetitions with an empty barbell (20 kg), followed by a 1-minute rest. Next, for familiarization purposes, 3 single repetitions at 40% of the subjects' self-estimated 1RM were performed with a 1-minute rest between trials. A linear encoder (Muscle l-ab, Ergotest Technology, version 8.31, Stathelle, Norway) was used to measure the subjects' maximal power. For data analysis, the peak value of the power curve was used to indicate the subjects' maximal power.

For the 1RM testing in the bench pull and bench press exercises, the exact same test setup was used as described above for the maximal power output test, except the use of the linear encoder. In both exercises, the subjects warmed up by performing 8 repetitions with the empty barbell (20 kg). Next, the load was increased by 10–30 kg depending on the individual's strength level, and 5 repetitions were performed. Subsequently, 3 submaximal single repetition bench pulls or presses with 80, 85 and 90% of the subjects' estimated 1RM were performed, with a 2-minute rest between each set. Finally, the subjects had 3 trials to reach 1RM, separated by a 3-minute rest. If the 3 trials succeeded with progression in load, the subjects made a fourth trial. Verbal encouragement was given during maximal attempts. An identical 1RM testing protocol, as described above, was used for the bench pull and bench press exercises in both study 1 and study 2. ICC and CV test-retest reliability measures were 0.99 and 0.23 for bench pull and 0.99 and 0.28 for bench press, respectively.

The purpose of the 40-second maximal repetition test was to assess how many repetitions the subjects could perform in 40 seconds with 40% of the previously established 1RM. The test was conducted in both the bench pull and bench press exercise. The setup used was identical to the maximal power output and 1RM test setup described above. A linear encoder (Muscle lab, Ergotest Technology, version 8.31, Stathelle, Norway) was used to measure the number of repetitions and the distance in which the barbell was moved. The outcome was computed as the total distance that the barbell had moved, which was expressed as a percentage of the individual's arm length. ICC and CV test-retest reliability measures were, unfortunately, not possible to compute for this test.

Training Protocol

In study 2, 2 separate 6-week training interventions were conducted. The subjects allocated to the TRAIN group performed 3 strength training sessions per week besides their regular kayak training. The strength training program aimed to increase the bench press 1RM because this was shown to be the best predictor of the 30-second sprint kayaking performance in study 1. Therefore, every training session consisted of 6 to 9 sets of 1 to 6 repetitions of heavy bench press (rating of perceived [RPE] = 7–9), with at least a 3- to 4-minute rest between sets (Table 1). Progression was made by increasing the load lifted and decreasing the repetitions performed per set throughout the duration of the intervention. Additionally, the strength training consisted of 3 to 4 sets of 8 to 10 repetitions (RPE = 7–8) of split squats and bent-over dumbbell reverse flyers or bench pull and single-arm shoulder press.

Table 1
Training program completed by the TRAIN group, aimed at increasing 1 repetition maximum in bench press.*†

	Week†					
	1	2	3	4	5	6
Day 1 and 3						
Bench press						
Number of sets	7	8	8	8	9	9
Repetitions	10,8,6,5,5,6,6	10,8,6,5,5,5,6,6	10,8,6,5,4,5,5,6	10,8,5,4,3,3,4,5	8,6,4,3,2,2,3,3,4	8,6,4,2,1,1,2,2,3
RPE	5,6,7,8,8,8,8	5,6,7,8,8,8,8	5,6,7,8,8,8,9,9	5,6,8,8,8,8,9,9	5,6,8,8,8,9,9,9,9	5,6,8,8,8,9,9,9,9
Interset rest	2,2,3,3,3,3	2,2,3,3,3,3	2,2,3,3,3,4,4	2,2,3,3,3,4,4	2,2,3,3,4,4,4,4	2,2,3,3,4,4,4,4
Split squat						
Number of sets	4	4	4	4	4	4
Repetitions	12,12,12,12	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10
RPE	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8
Interset rest	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3
Reverse flyers						
Number of sets	4	4	4	4	4	4
Repetitions	12,12,12,12	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10
RPE	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8
Interset rest	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3
Day 2						
Bench press						
Number of sets	7	8	8	8	9	9
Repetitions	10,8,6,5,5,6,6	10,8,6,5,5,5,6,6	10,8,6,5,4,5,5,6	10,8,5,4,3,3,4,5	8,6,4,3,2,2,3,3,4	8,6,4,2,1,1,2,2,3
RPE	5,6,7,8,8,8,8	5,6,7,8,8,8,8	5,6,7,8,8,8,9,9	5,6,8,8,8,8,9,9	5,6,8,8,8,9,9,9,9	5,6,8,8,8,9,9,9,9
Interset rest	2,2,3,3,3,3	2,2,3,3,3,3	2,2,3,3,3,4,4	2,2,3,3,3,4,4	2,2,3,3,4,4,4,4	2,2,3,3,4,4,4,4
Bench pull						
Number of sets	4	4	4	4	4	4
Repetitions	12,12,12,12	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10
RPE	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8
Interset rest	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3
Single-arm shoulder press						
Number of sets	4	4	4	4	4	4
Repetitions	12,12,12,12	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10	12,10,10,10
RPE	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8	5,7,7,8
Interset rest	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3	2,2,3

*RPE = rate of perceived exertion.
†Interset rest indicates a rest period between sets in minutes.

The subjects allocated to the MAIN group performed 2 identical strength training sessions per week besides their regular kayak training. The strength training program aimed to maintain the current strength levels in the exercises conducted. The volume, intensity, and the frequency of the training intervention were deliberately set lower than those in the training program for the TRAIN group to minimize exercise stimuli but still to create the illusion of performing a progressive intervention. Therefore, every strength training session consisted of 3 to 4 sets of 8 to 12 repetitions (RPE = 6–7). The exercises incorporated were split squats, bench pull, bench press, reverse flyers, single-arm shoulder press, and single-arm lateral pull down (Table 2).

In both training programs, the intensity was specified by means of the RPE scale. The RPE scale is a 10-point numeric scale, with 10 indicating maximal intensity and 1 indicating the lowest possible intensity. This scale has previously been validated as a subjective measure of lifting intensity in both experienced and novice strength training athletes (22). The strength training sessions were supervised and took place twice per week in predetermined time slots. Unfortunately, not all subjects were able to complete all training sessions during the supervised time slots. Instead, they completed the given training sessions on their own. All subjects kept a meticulous training log noting all training sessions performed, including details on volume and intensity of training.

All subjects continued their normal kayak training during the training intervention. This training was based on the kayak training program supplied by the head coach of each of the 3 regional kayak training centers. Thus, kayak-specific training could not be controlled for. However, to counteract any differences brought about by differences in kayak training, the subjects were stratified based on the kayak center to which they belonged.

Statistical Analyses

To test the hypothesis in study 1, a regression model was applied to test the relationship between the dependent variable (30-second on-water kayak sprint performance) and the independent variables (isometric force, maximal power output, 1RM, and 40-second maximal repetitions in bench pull and bench press). Because of the presence of multicollinearity of the independent variables in the data set, it was not possible to apply a normal multiple regression analysis. Instead, a partial least square regression analysis (PLS) was applied because this method is capable of handling data sets exhibiting multicollinearity (20).

To test the hypothesis in study 2, a Mann-Whitney U test was first used to test whether the groups were statistically different from each other for all 5 variables (200 m sprint performance, 1RM bench pull, and 1RM bench press) at the pre- and posttest. Then, a paired-samples *t* test or a Wilcoxon's test was used to test

Table 2
Training program completed by the MAIN group aimed to maintain strength levels in all exercises.*†

	Week					
	1	2	3	4	5	6
Day 1 and 2						
Split squat						
Number of sets	4	4	4	4	5	5
Repetitions	12, 12, 12, 12	12, 12, 12, 12	12, 12, 10, 10	12, 10, 10, 10	12, 10, 10, 10, 8	12, 10, 10, 8, 8
RPE	5, 6, 6, 7	5, 7, 7, 8	5, 6, 6, 7	5, 7, 7, 8, 8	5, 7, 7, 8, 8	5, 7, 7, 8, 8
Interset rest	2, 2, 2	2, 2, 3	2, 2, 2	2, 2, 3	2, 2, 3, 3	2, 2, 3, 3
Bench pull						
Number of sets	3	3	3	3	3	3
Repetitions	12, 12, 12	12, 12, 12	12, 12, 10	12, 10, 10	12, 10, 10	12, 10, 10
RPE	5, 6, 6	5, 7, 7	5, 6, 6	5, 7, 7	5, 7, 7	5, 7, 7
Interset rest	2, 2	2, 2	2, 2	2, 2	2, 2	2, 2
Bench press						
Number of sets	3	3	3	3	3	3
Repetitions	12, 12, 12	12, 12, 12	12, 12, 10	12, 10, 10	12, 10, 10	12, 10, 10
RPE	5, 6, 6	5, 6, 7	5, 5, 6	5, 7, 7	5, 7, 7	5, 7, 7
Interset rest	2, 2	2, 2	2, 2	2, 2	2, 2	2, 2
Reverse flyers						
Number of sets	4	4	4	4	4	4
Repetitions	12, 12, 12, 12	12, 10, 10, 10	12, 10, 10, 10	12, 10, 10, 10	12, 10, 10, 10	12, 10, 10, 8
RPE	5, 6, 6, 7	5, 7, 7, 8	5, 6, 6, 7	5, 7, 7, 8	5, 7, 7, 8	5, 7, 7, 8
Interset rest	2, 2, 3	2, 2, 3	2, 2, 3	2, 2, 3	2, 2, 3	2, 2, 3
Single-arm shoulder press						
Number of sets	4	4	4	4	5	5
Repetitions	12, 12, 12, 12	12, 12, 12, 12	12, 12, 10, 10	12, 10, 10, 10	12, 10, 10, 10, 8	12, 10, 10, 8, 8
RPE	5, 6, 6, 7	5, 7, 7, 8	5, 6, 6, 7	5, 7, 7, 8, 8	5, 7, 7, 8, 8	5, 7, 7, 8, 8
Interset rest	2, 2, 2	2, 2, 3	2, 2, 2	2, 2, 3	2, 2, 3, 3	2, 2, 3, 3
Single-arm lat pulldown						
Number of sets	4	4	4	4	5	5
Repetitions	12, 12, 12, 12	12, 12, 12, 12	12, 12, 10, 10	12, 10, 10, 10	12, 10, 10, 10, 8	12, 10, 10, 8, 8
RPE	5, 6, 6, 7	5, 7, 7, 8	5, 6, 6, 7	5, 7, 7, 8, 8	5, 7, 7, 8, 8	5, 7, 7, 8, 8
Interset rest	2, 2, 2	2, 2, 3	2, 2, 2	2, 2, 3	2, 2, 3, 3	2, 2, 3, 3

*RPE = rate of perceived exertion.
†Interset rest indicates a rest period between sets in minutes.

for statistical differences between the pre- and posttest for each group depending on the normality of the data. Data are presented as mean ± SD. Statistical significance was accepted at $p \leq 0.05$. All statistical computations were performed in SPSS version 25.0 (IBM Corp; Armonk, NY).

Results

In study 1, 4 subjects were excluded owing to personal issues unrelated to the study. Therefore, results from 33 subjects were included in the statistical analysis. Distance completed within 30 seconds of on-water kayaking was 137.0 ± 13.8 m. Force output during isometric bench press and bench pull was 1,443.4 ± 379.9 Newton (N) and 1,677.7 ± 414.2 N, respectively. Maximal power output during bench press and bench pull was 354.7 ± 107.2 Watt (W) and 535.5 ± 144.2 W, respectively. Expressed as a percentage of the individual's arm length, the total distance that the barbell had travelled during the 40-second repetition number test for bench press and bench pull was 3,075.4 ± 359.2% and 3,726.5 ± 432.7%, respectively. Finally, 1RM in bench press and bench pull was 81.7 ± 22.0 and 78.5 ± 16.6 kg, respectively. All results for study 1 are also shown in Table 3 for male and female padders, respectively.

In the partial least square regression analysis performed in study 1, latent factor 1 was used because it explained most of the variance alone. The proportion of variance explained in the model was 64.1% for the independent variables (x variance) and 61.7% for the dependent variable (y variance). The proportion of variance explained for the whole model was 60.4% (adjusted R^2). Table 4 shows the main result of the partial least square regression analysis. Each independent variable used in the model is listed along with its corresponding regression coefficient in relation to the 30-second on-water kayak sprint test. Variable importance in the projection (VIP) values are also listed. These values explain the importance of each independent variable in relation to the projection of the model. The model shows that the 1RM bench press and 1RM bench pull are the only independent variables capable of predicting performance in a 30 seconds on-water kayak sprint test. Furthermore, these 2 variables are very important in the model (VIP: 1.291 and 1.202, respectively). The model shows that among the 4 different strength test outputs, 1RM strength is a better predictor of performance in a 30-second on-water kayak sprint test than isometric strength, maximal power output, and the maximal number of repetitions performed within 40 seconds. Moreover, 1RM in bench press seems to be a stronger predictor than 1RM in bench pull. As a result, it was decided that the aim of TRAIN in study 2 would be to increase 1RM in bench press to test whether this would have a positive effect on kayak sprinting performance.

In study 2, 5 subjects were excluded owing to personal issues unrelated to the study, and one subject was excluded owing to technical problems at the posttest. Unfortunately, all excluded subjects belonged to MAIN. Therefore, a total of 20 subjects were

Table 3

Mean results for male and female paddlers of all independent variables tested in study 1.*

Independent variable	Male	Female
On-water distance covered in 30 seconds (m)	145.3 ± 9.5	127.0 ± 10.2
1RM, bench press (kg)	96.5 ± 17.2	62.6 ± 8.4
1RM, bench pull (kg)	90.5 ± 10.2	64.0 ± 9.6
Force, isometric bench press (N)	1713.6 ± 304.5	1,137.2 ± 156.7
Force, isometric bench pull (N)	1941.7 ± 354.2	1,360.8 ± 206.4
Maximal power, bench press (W)	433.3 ± 74.1	260.4 ± 46.3
Maximal power, bench pull (W)	642.8 ± 82.3	406.6 ± 81.9
40-seconds maximal repetition number test, bench press (%)	3,069.3 ± 385.7	3,083.3 ± 336.1
40-seconds maximal repetition number test, bench pull (%)	3,835.9 ± 391.5	3,595.4 ± 456.0

*1RM = 1 repetition maximum; s = seconds, m = meter, N = Newton. W = watt.

included in the statistical analysis, 14 from the TRAIN and 6 from the MAIN groups. A total of 341 individual training sessions were conducted; of which, 111 were supervised. An analysis of the subjects' training logs revealed that all subjects had completed all training sessions in the prescribed manner, resulting in 100% training compliance. On average, TRAIN completed a total of 24.5 sets of bench press training with an average RPE score of 7.6 per week, whereas MAIN completed a total of 6 sets of bench press training with an average RPE score of 6.0 per week.

The results of the six-week training intervention are presented in Figure 1. There were no significant differences in the 1RM bench press, 1RM bench pull, or 200-m kayak ergometer sprint test time between TRAIN and MAIN at pre- and posttest ($p \geq 0.05$), respectively. TRAIN significantly increased 1RM strength in bench press (pre: 87.3 ± 21.2 kg, post: 93.9 ± 21.3 kg, $p = 0.001$) and bench pull (pre: 84.2 ± 15.3 kg, post: 86.0 ± 15.1 kg, $p = 0.025$) from pre- to posttest. No significant differences were observed in MAIN from pre- to posttest, neither in 1RM strength in bench press (pre: 93.3 ± 26.5 kg, post: 94.6 ± 28.7 kg, $p = 0.408$) nor in 1RM in bench pull (pre: 85.4 ± 21.2 kg, post: 86.6 ± 20.2 kg, $p = 0.461$). In the 200-m kayak ergometer sprint test, TRAIN significantly reduced the time to complete the test (pre: 44.8 ± 4.3 seconds, post: 44.3 ± 4.3 seconds, $p = 0.042$), whereas no significant difference in performance was observed in MAIN (pre: 45.7 ± 4.4 seconds, post: 45.6 ± 5.3 seconds, $p = 0.89$).

Discussion

This study investigated which type of strength test in bench press and bench pull was the best predictor of 30-second on-water kayak sprint performance. It was shown that 1RM in bench press was the best predictor because it had the highest regression coefficient and VIP value of the PLS model. A 6-week training intervention was conducted to elucidate the causal relationship between an increase in 1RM bench press and a concomitant increase in 200-m kayak sprint performance. As hypothesized, TRAIN significantly increased the 1RM in bench press and significantly reduced the time to complete a 200-m kayak ergometer sprint, whereas no significant changes were observed in MAIN.

In study 1, 1RM strength in bench press, and to a lesser extent 1RM in bench pull, was the best predictor of 200-m on-water kayaking performance, whereas the PLS model showed negligible effects of the isometric force, maximal power output, and 40-second maximal repetition test. The importance of 1RM strength in kayaking performance shown in this study was in line with our first hypothesis and is also in accordance with several other studies (13,15). However, this is in contrast to the results of Acka et al. (21), who did not find a significant correlation between 1RM in bench press and 200-m kayaking performance (1). A possible explanation for this contradiction is that bench press was assessed using only the concentric phase of the lift in the study by Acka et al. (21) and thus not including the eccentric phase of the lift as in the present study. Because the eccentric phase is important for eliciting the highest possible 1RM (21), the omission could have led to lower 1RM values in bench press, which may explain the differing results. However, Acka et al. (21) did find that 1RM in bench pull had a significant correlation with 200-m kayaking performance, which is in accordance with the results of the present study, in which 1RM in bench pull was the second-best predictor.

Several other studies have shown significant correlations between isometric force (12), maximal power output (3), and maximal repetition tests (1) in bench press, bench pull, and kayak sprint performance. In combination with the results of the present study, these studies indicate that high strength levels in the upper body, assessed using different tests, seem to be important for

Table 4

Regression coefficients and variable importance in the projection (VIP) values of the partial least squares regression analysis model for alle independent variables.*

Independent variable	Regression coefficients	VIP
1RM, bench press (kg)	0.474	1.291
1RM, bench pull (kg)	0.216	1.202
Force, isometric bench press (N)	0.001	1.085
Force, isometric bench pull (N)	0.004	0.992
Maximal power, bench press (W)	0.021	1.232
Maximal power, bench pull (W)	−0.045	1.058
40 seconds maximal repetition number test, bench press (%)	−0.007	0.300
40 seconds maximal repetition number test, bench pull (%)	0.007	0.011

*1RM = 1 repetition maximum; N = Newton. W = watt.

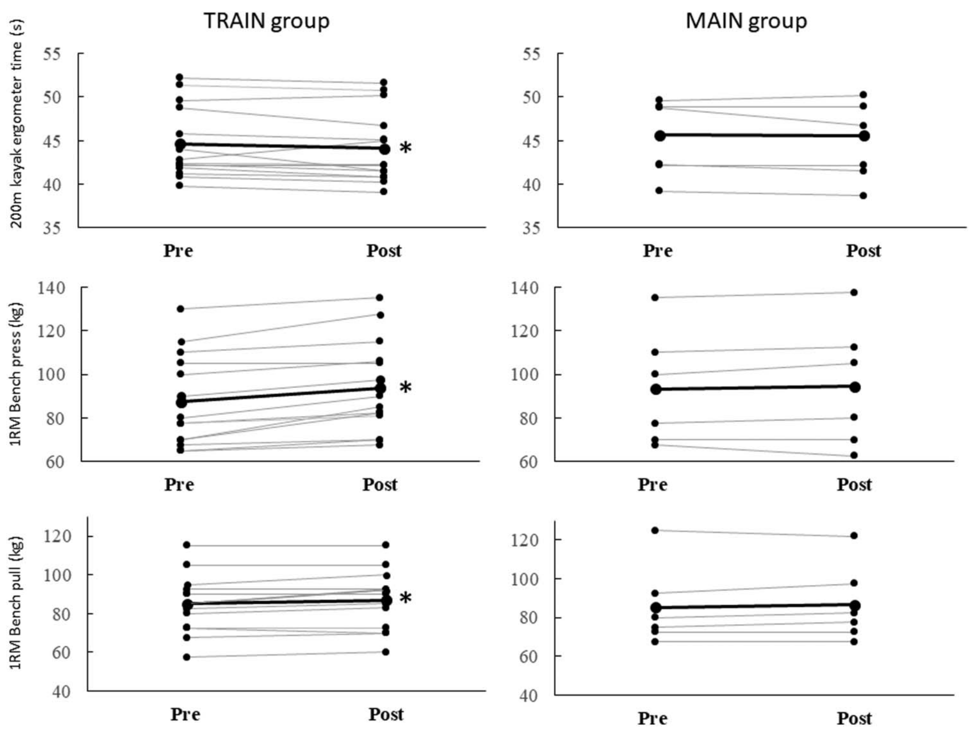

Figure 1. Change in 200-m kayak ergometer time, 1 repetition maximum (1RM) in bench press, and 1 RM in bench pull from pre- to posttest in the TRAIN and MAIN groups. Grey lines represent individual data points. Black lines represent the group averages. *Significant difference from pretest to posttest ($p < 0.05$).

kayak sprint performance. In the present study, we investigated all these tests in the same population and found that 1RM strength was the best predictor of kayaking performance. Moreover, we also found the data set to exhibit multicollinearity meaning that all the strength tests were highly correlated. From a theoretical perspective, this makes sense as absolute strength (i.e., 1RM) in any given exercise is a prerequisite if one is to also exhibit a high amount of isometric force, maximal power output, or perform as many repetitions as possible in a given time frame in the same exercise (18). Thus, a major strength of this study is the use of the PLS model because it enables the reduction of dimensions in the data set and identification of covariance between independent variables and the dependent variable (2). As such, the model is ideally suited to filter out the independent variables that have true meaning in predicting the dependent variable.

Regardless of the obvious advantages of implementing the PLS model in study 1, no model is better than the input it receives. Despite proper input, no regression model can confirm causality between independent and dependent variables. Because 1RM in bench press displayed the highest predictive capabilities, the logical next step in study 2 was to further explore this by performing a randomized, controlled, intervention study. As a result, significant increases in 1RM bench press, 1RM bench pull, and 200-m kayak ergometer performance were observed. These results support the second hypothesis of this study. Furthermore, they are in accordance with other studies that have induced increases in upper-body strength and seen a concomitant improvement in kayak sprint performance (11,12). The fact that an increase in 1RM in bench pull was observed in TRAIN was not expected, especially because TRAIN only performed 4 sets of bench pull per week compared with MAIN performing 6 sets per week. However, the intensity of the bench pull training was slightly higher for TRAIN compared with MAIN. This may explain why a significant increase was observed because the intensity of lifting has previously been shown to be essential for increases in strength (19). In comparison, the effect size for bench press (0.31) was higher than that of bench pull (0.12), which may indicate that the significant improvement in 200-m kayak ergometer performance is more likely to have been a result of increased bench press strength than increased bench pull strength. One possible explanation for the fact that an increase in bench press 1RM was the best predictor in study 1 and could bring about a performance improvement in kayak ergometer sprint performance in study 2 is related to the role of the top hand during the pull phase of the kayak stroke. In the pull phase, the top hand creates a force vector pointing downward along the paddle shaft to counteract the vertical reaction forces encountered at the end of the blade known as lift force (9,14). The force vector created by the top hand is the result of a horizontal adduction of the upper arm, and an extension of the elbow joint. In this movement, the pectoralis major, anterior deltoideus, and triceps brachii muscles are considered agonist muscles, just like they are considered agonist muscles in the bench press exercise. Therefore, increased strength levels of the muscles coordinating the top hand may also increase the forces created along the paddle shaft to resist the lift forces created at the blade, thereby increasing the effectiveness of the pull phase and thus performance.

A limitation of the current research is that a 30-second on-water kayak sprint test was used in study 1, whereas a 200-m kayak ergometer sprint test was used in study 2. Because the mean time to complete the 200-m kayak ergometer sprint was approximately 45 seconds, this may have increased the contribution from the aerobic energy system slightly while decreasing the contribution from the anaerobic energy system. Similarly, some kinematic differences have been observed between on-water and ergometer paddling (10). However, these differences are not likely to have had any major effect on the overall interpretation of the outcome of the current study because performances in the 2 tests are highly correlated (16).

During the on-water kayak sprint test in study 1, factors such as wind speed and wind direction could not be controlled for because the test was conducted outside. To ensure that the conditions were as similar as possible for all the subjects, the wind speed and wind direction were measured before each test and the physical location and direction of the sprint was moved around the lake to accommodate for the best possible conditions for each subject. Therefore, it is unlikely that the weather conditions had a major effect on the results.

In conclusion, study 1 showed that 1RM in bench press was the best predictor of 200-m on-water kayak sprint performance, whereas 1RM in bench pull was the second-best predictor. Strength tests of isometric force, maximal power output, and the maximal number of repetitions performed during 40 seconds of bench press and bench pull were not able to predict kayak sprinting performance. In study 2, 6 weeks of strength training, aiming at increasing upper-body strength, resulted in a significant increase of 1RM in bench press, 1RM of bench pull, and 200-m kayak ergometer sprint performance. Performing 6 weeks of strength training with the aim of maintaining strength resulted in no significant differences. This is the first study to elucidate the relationship between performance in different tests of strength in the bench press and bench pull exercise and their ability to predict performance in sprint kayaking while subsequently testing this in a controlled training intervention study.

Practical Applications

The results of the present study indicate that upper-body strength is important for optimal performance in the 200 m flat-water sprint kayak discipline. When testing upper-body strength, focus should be on testing 1RM dynamic strength in the bench press and bench pull exercises because these are the best predictors of the performance. Similarly, the strength training of 200-m sprint kayakers should focus on increasing 1RM strength in the bench press exercise because this may improve the kayaking performance. The bench press–specific training program provided in Table 1 may serve as a starting point for strength and condition coaches wishing to enhance bench press strength in elite kayakers.

Acknowledgments

The authors thank the subjects for their cooperation and contributions. Furthermore, the authors thank Team Denmark for covering transport expenses associated with the data collection. Other than that, no specific funding was received for the present work. No specific funding was received to support the present work. However, Team Danmark supported the study by covering transportation expenses related to the training intervention.

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