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An investigation into the effects of excluding the catch phase of the power clean on force-time characteristics during isometric and dynamic tasks: an intervention study

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Running header: Effects of excluding the catch phase of the power clean: an intervention study

An investigation into the effects of excluding the catch phase of the power clean on force-time characteristics during isometric and dynamic tasks: an intervention study

Abstract

The aims of this study were to compare the effects of the exclusion or inclusion of the catch phase, during power clean (PC) derivatives, on force-time characteristics during isometric and dynamic tasks, after two, four-week mesocycles of resistance training. Two strength matched groups, completed the twice weekly training sessions, either including the catch phase of the PC derivatives (Catch: n = 16; age 19.3 ± 2.1 years; height 1.79 ± 0.08 m; body mass 71.14 ± 11.79 kg; PC one repetition maximum [1-RM] 0.93 ± 0.15 kg.kg^{-1}) or excluding the catch phase (Pull: n = 18; age 19.8 ± 2.5 years; height 1.73 ± 0.10 m; body mass 66.43 ± 10.13 kg; PC 1RM 0.91 ± 0.18 kg.kg^{-1}). The Catch and Pull groups both demonstrated significant ($p \leq 0.007$, power ≥ 0.834) and meaningful improvements in countermovement jump (CMJ) height (10.8 ± 12.3%, 5.2 ± 9.2%), isometric mid-thigh pull (IMTP) performance (force [F]100: 14.9 ± 17.2%, 15.5 ± 16.0%, F150: 16.0 ± 17.6%, 16.2 ± 18.4%, F200: 15.8 ± 17.6%, 17.9 ± 18.3%, F250: 10.0 ± 16.1%,10.9 ± 14.4%, PF: 13.7 ± 18.7%, 9.7 ± 16.3%) and PC 1RM (9.5 ± 6.2%, 8.4 ± 6.1%), pre- to post-intervention, respectively. In contrast to the hypotheses, there were no meaningful or significant differences in percentage change, for any variables, between groups. This study clearly demonstrates that neither the inclusion nor exclusion of the catch phase of the PC derivatives result in any preferential adaptations over two 4-week, in-season strength and power, mesocycles.

Key Words: Countermovement Jump; Weightlifting; Performance; Training

INTRODUCTION

Weightlifting exercises (snatch and clean and jerk) and their derivatives are commonly performed in athletes' training programs, with performance in such exercises reported to be related to athletic tasks, such as sprint, agility and jump performances (29, 40). These positive associations to performances in athletic tasks may be due to the previously reported similarity in kinetics between weightlifting derivatives (hang snatch) and jump performances (4), with similar observations reported between the second pull phase of the snatch and jump performances by Garhammer and Gregor (18).

Observations of weightlifting performances have established that the second pull phase of the clean and snatch elicits the greatest peak power, compared to the other phases of the lifts (18), albeit using barbell velocity and inverse dynamics to assess peak power applied to it. Furthermore, peak force (PF) and rate of force development (RFD) have also been shown to occur during the second pull phase of the clean and clean pull (16, 39). More recently, the mid-thigh power clean (PC) and mid-thigh pull have been shown to result in significantly greater (p <0.001) PF, peak RFD (5) and peak power applied to the lifter plus bar system (6) when compared to the hang power clean and PC. Moreover, no significant (p > 0.05) differences were observed between these lifts irrespective of the inclusion or exclusion of the catch phase (5, 6). In addition, Suchomel et al. (47) reported that the jump shrug, (similar to the mid-thigh pull but initiated with a countermovement and the athlete actually leaves the ground) resulted in significantly (p < 0.05) greater PF, peak velocity, and peak power compared to the hang power clean and hang high pull across all loads (30, 45, 65, 80% one repetition maximum [1RM] hang clean), indicating that the removal of a catch phase during a PC derivative is not detrimental to the peak power achieved. Similarly, additional studies by Suchomel et al. (45, 46) also reported greater relative PF, power, impulse, work, and peak RFD in the jump shrug compared to the hang power clean and hang high pull across loads (30, 45, 65, 80% 1RM hang clean). More recently, researchers have examined these differences at the joint-level, with Kipp et al. (32) indicating that the jump shrug produces greater magnitudes of joint work and power compared to the hang power clean across several loads.

Recent reviews of weightlifting derivatives also suggested that variations of the PC, which omit the catch phase, namely the clean pull, mid-thigh pull, jump shrug and hang high pull, may be advantageous when training athletes who are less proficient with full weightlifting movements that include the catch phase (41, 43). This is supported by additional research that has suggested the use of associate exercises that enhance explosive strength during the second pull movement in less skillful athletes (25). Based on the kinetic similarities of the propulsion phases of the clean derivatives performed with and without the catch phase, it would be feasible to suggest that the elimination of the catch phase should not be detrimental during a training program. In fact, the elimination of the catch phase may provide the opportunity for the athlete to ensure full triple extension of the hips, knees and ankles (plantar flexion), without the possibility of terminating the propulsion phase early to initiate the catch. Ultimately, this may lead to superior training adaptations with regard to PF, RFD, and power during the triple extension movement.

Additionally, the catch phase of the weightlifting derivatives has been suggested to be potentially beneficial in terms of training deceleration and eccentric loading; however, the loading during the catch has been reported to only be comparable to landing during a drop jump (36). More recently, the clean pull from the knee was shown to result in greater mean forces during the load absorption phase compared to the clean and PC from the knee (11). Similarly, Suchomel et al. (44) recently reported greater mean forces during the load absorption phase of the jump shrug compared to the hang high pull and hang power clean. The findings of these studies refute the notion that the catch phase of the clean provides effective eccentric loading. To date, however, there are no published intervention studies that compare the effectiveness of including or excluding the catch during weightlifting derivatives on strength and power characteristics.

The aims of this study, therefore, were to compare the effects of the exclusion or inclusion of the catch phase, during PC derivatives, on force-time characteristics during isometric and dynamic tasks, after two, four-week mesocycles of resistance training. It was hypothesized that both groups would improve across all variables, but that the Pull group (elimination of the catch phase) would result in greater improvements in force-time characteristics assessed during isometric and dynamic performance between groups, compared to the Catch group.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

To determine the effect of the training interventions, on force-time characteristics during isometric and dynamic tasks, a repeated-measures within subject design was utilized, with subjects assessed twice at baseline (48-72 hours apart) to determine reliability, after the initial four week mesocycle, and again after the second four week mesocycle (Figure 1). Furthermore, a between-subjects experimental approach was used to determine differences in changes between intervention groups (Pull vs. Catch). All testing and training occurred in-season, during the middle of the season for each sport. Data was collected across multiple venues, using the same portable equipment, by the same group of researchers.

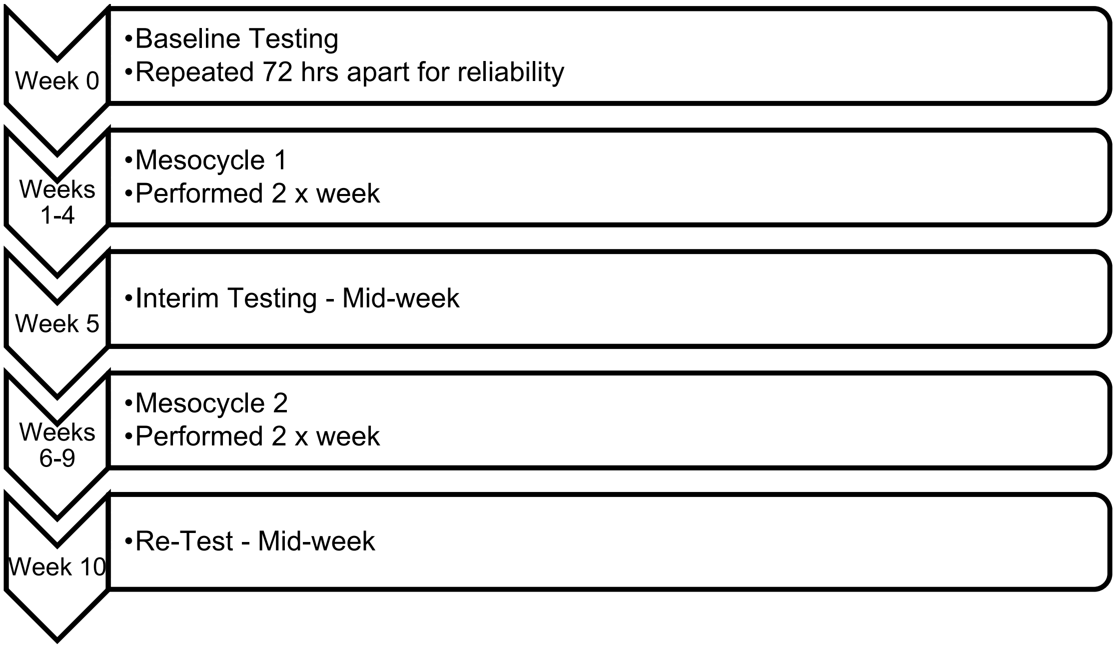


Figure 1: Summary of testing schedule

Subjects

Professional youth soccer players (n = 18) and collegiate athletes (n = 26), from the United Kingdom, initially volunteered to participate in this investigation. All subjects were experienced (training age: 3.1 ± 1.2 years) and competent in each of the lifts performed in the interventions, as determined by a certified strength and conditioning specialist. After baseline testing subjects were divided into the two groups by matching relative 1RM PC performances, with an equal number of athletes from each sport in both groups. Due to injury from competition and or illness across the duration of the intervention the number of subjects to complete the entire study reduced to 11 professional male soccer players and 23 collegiate athletes who participated in a variety of sports (BMX, rowing, field hockey). Due to drop out, the final mean 1RM PC performance for the groups differed slightly; Catch (n = 16, 12 male, 4 female [5 soccer, 3 BMX, 6 rowing, 2 field hockey]; age 19.3 ± 2.1 years; height 1.79 ± 0.08 m; body mass 71.14 ± 11.79 kg; 1RM PC 0.93 ± 0.15 kg.kg^{-1}) Pull (n = 18, 14 male, 4 female [6 soccer, 2 BMX, 7 rowing, 2 field hockey]; age 19.8 ± 2.5 years; height 1.73 ± 0.10 m; body mass 66.43 ± 10.13 kg; 1RM PC 0.91 ± 0.18 kg.kg^{-1}). A minimum of 11 subjects per groups was required for an *a priori* power ≥0.80, at an alpha level of $p \leq 0.05$, with post hoc power presented in the results section. This study was approved by the institutional review board, in accordance with the declaration of Helsinki. All subjects provided written informed consent, or parental assent as appropriate.

PROCEDURES

Prior to testing subjects performed a non-fatiguing standardized warm up consisting of body weight squats, forward and reverse lunges, submaximal squat jumps (SJ) and countermovement jumps (CMJ). Further familiarization and warm up trials were performed prior to the maximal isometric mid-thigh pull (IMTP) and 1RM PC as described below. After the completion of the warm up subjects performed the SJ, CMJ, IMTP and 1RM PC as described below; with testing performed in this sequence to minimize the risk of fatigue or potentiation (Figure 2). All subjects were familiar with all testing procedures as these were included in their 'normal' testing and monitoring procedures. All assessments were conducted by the same experienced researchers.

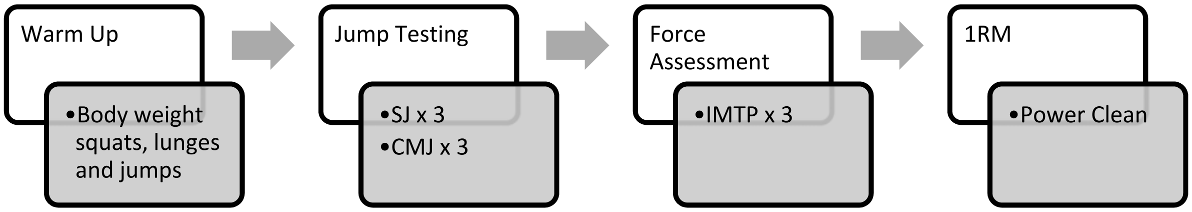


Figure 2: Testing sequence

Jump Performances

Both SJ and CMJ performances were assessed with subjects standing on a Kistler force platform, sampling at 1000 Hz, with data collected via Bioware 5.11 software (type 9286AA, Kistler Instruments Inc., Amherst, NY, USA). Subjects were instructed to stand still for the initial one second of data collection (35, 38) to enable the subsequent determination of body weight (vertical force averaged over one second). Subjects performed three maximal efforts SJ and CMJ, with a one-minute rest between trials and a three-minute rest between the SJ and CMJ. Raw unfiltered, force-time data was exported for subsequent analysis.

For the SJ, subjects placed their hands akimbo, squatted down to a self-selected depth of approximately 90˚ knee joint angle, paused for 3 seconds and then jumped as high as possible after a countdown of, ‘3, 2, 1, jump’. If there was any obvious countermovement, following visual inspection of the force-time data the jump was excluded, and the subject preformed an additional trial after a one-minute rest.

For the CMJ, subjects were instructed to perform the jumps as fast and as high as possible, whilst keeping their arms akimbo. Any jumps that were inadvertently performed with the inclusion of arm swing or leg tucking during the flight phase were omitted and additional jumps were performed after one minute of rest.

Isometric Mid-thigh Pull Assessment

For the IMTP, the procedures previously described by Haff et al. (20, 21) were used. The minor differences in knee joint angle, which result from differences in ankle dorsiflexion, have been shown to have minimal effect on kinetic variables during the IMTP (7). It was ensured, however, that each subject adopted the posture that they would use for the start of the second pull phase of the clean resulting in knee and hip angles of 133.1 ± 6.6˚ and 145.6 ± 4.8˚ respectively, in line with previous research (3, 21). Individual joint angles were recorded and standardized between testing sessions, in line with previous suggestions (3, 15). Briefly, for this test, an immovable cold rolled steel bar was positioned at a height, which replicates the start of the second pull phase of the clean, with the bar fixed above the force platform to accommodate different sized participants. Once the bar height was established, the subjects’ stood on the force platform with their hands strapped to the bar in accordance with previously established methods (2). Each participant performed two warm-up pulls, one at 50%, and one at 75% of the participant’s perceived maximum effort, separated by one minute of rest.

Once body position was stabilized (verified by watching the participant and force trace), the participants were given a countdown of “3, 2, 1, Pull!”. Minimal pre-tension was permitted to ensure there was no slack in the participant’s body prior to initiation of the pull, with the instruction to pull against the bar ”as fast and hard as possible” (24), and push the feet down into the force plate; this instruction has been previously found to produce optimal testing results (23). Each IMTP trial was performed for approximately five seconds, and all participants were given strong verbal encouragement during each trial. Participants performed three maximal IMTP trials interspersed with two minutes of rest between trials. If PF during all trials did not fall within 250 N of each other, the trial was discounted and repeated after a further two minutes of rest, in line with previous recommendations (19, 21).

Vertical ground reaction force data for the IMTP was collected using a portable force plate sampling at 1000 Hz (Kistler Instuments, Winterthur, Switzerland), interfaced with a laptop computer and specialist software (Bioware 5.11, Kistler Instruments, Winterthur, Switzerland) that allows for direct measurement of force-time characteristics. Raw unfiltered, force-time data was exported for subsequent analysis.

One Repetition Maximum Power Clean

The 1RM PC performances were determined based on the standardized NSCA protocol (1). Briefly, subjects performed warm-up PC sets using sub maximal loads prior to performing a maximal attempt, with a progressive increase in loading during the maximal attempts (International Weightlifting Federation, accredited bars and plates were used throughout). Any power clean repetition caught with the top of the subject's thighs below parallel was ruled as an unsuccessful attempt.

DATA ANALYSIS:

Kinetic and Kinematic Variables

Raw force-time data for both the jumps and the IMTP were analyzed in Microsoft Excel (Excel 2016, Microsoft, Washington, USA). Jump height was calculated from velocity of center of mass at take-off, for both the SJ and CMJ (35). Center of mass velocity was determined by dividing vertical force data (minus body weight) by body mass and then integrating the product using the trapezoid rule. The start of the CMJ was identified in line with current recommendations (38). Take-off was identified when vertical force decreased below five times the standard deviation of the force during the flight phase (residual force) (34).

Reactive strength index modified (RSImod) was calculated using the methods described by previous research (34), where jump height is divided by time to take off ([TTT] combined countermovement, braking and propulsion phase time) during the CMJ.

The maximum forces recorded from the force-time curve during the IMTP trials were reported as the PF and subsequently ratio scaled (PF / body mass). The onset of force production was defined as an increase in force greater than five standard deviations of force during the period of quiet standing (13), and subsequently force at 100-, 150-, 200- and 250 ms (F100, F150, F200, F250) were also determined and ratio scaled. The average value of the three trials was used for statistical analyses.

INTERVENTION

Participants were divided into either the Pull group or Catch group and performed the prescribed training on two days per week, under the supervision of certified strength and conditioning specialists. The program consisted of two, 4-week mesocycles (Tables 1 & 2). The relative training intensity for each group was matched in an attempt to equate the volume-load completed by each group. The loads prescribed for all pulling and catching derivatives were based on the subjects' 1RM PC. The loads prescribed for the remaining exercises were based on predicted 1RM loads based on the subject's previous 5RM performances as determined at the end of their previous phase of training. The volume load during the second session was reduced, as this was the session closest to the subjects' day of competition. All training sessions were supervised by at least one of the authors, who were qualified strength and conditioning coaches (either as a certified strength and conditioning coach with the National Strength and Conditioning Association, an accredited strength and conditioning coach with the United Kingdom Strength and Conditioning Association, or both), to ensure consistency of performance.

The rowers and professional youth soccer players performed between 10-14 hours of skill and conditioning based training per week, in addition to the intervention; while the other subjects performed between 5-8 hours per week of additional training, dependent on their competition schedule, hence initially dividing the subjects equally across groups.

Table 1: Training sessions, weeks 1-4

Mesocycle 1: Day 1				
Exercise	Week 1	Week 2	Week 3	Week 4
Back Squat	3 x 5 @ 75%	3 x 5 @ 80%	3 x 5 @ 82.5%	3 x 5 @ 67.5%
Power Clean / Clean Pull[a]	3 x 5 @ 75%	3 x 5 @ 80%	3 x 5 @ 82.5%	3 x 5 @ 67.5%
Push Press	3 x 5 @ 70%	3 x 5 @ 72.5%	3 x 5 @ 75%	3 x 5 @ 60%
Nordic Lowers	2 x 3 BW	3 x 3 BW	3 x 3 BW	3 x 3 BW
Mesocycle 1: Day 2				
Mid-thigh Power Clean / Mid-thigh Pull[b]	3 x 5 @ 60%	3 x 5 @ 65%	3 x 5 @ 70%	3 x 5 @ 55%
RDL	3 x 5 @ 70%	3 x 5 @ 75%	3 x 5 @ 77.5%	3 x 5 @ 62.5%
Sets x Repetitions @ 1RM % BW = Body Weight **[a]Power clean for the Catch group / Clean pull for the Pull group** **[b]Mid-thigh power clean for the Catch group / Mid-thigh pull for the Pull group**				

Table 2: Training sessions, weeks 6-9

Mesocycle 2: Day 1				
Exercise	Week 1	Week 2	Week 3	Week 4
Power Clean / Clean Pull[a]	3 x 3 @ 80%	3 x 3 @ 85%	3 x 3 @ 90%	3 x 3 @ 75%
Push Press	3 x 3 @ 80%	3 x 3 @ 82.5%	3 x 3 @ 85%	3 x 3 @ 75%
Back Squat	3 x 3 @ 82.5%	3 x 3 @ 87.5%	3 x 3 @ 90%	3 x 3 @ 75%
Nordic Lowers	2 x 3 BW	3 x 3 BW	3 x 3 BW	3 x 3 BW
Mesocycle 2: Day 2				
Mid-thigh Power Clean / Mid-thigh Pull[b]	3 x 3 @ 80%	3 x 3 @ 82.5%	3 x 3 @ 85%	3 x 3 @ 70%
RDL	3 x 3 @ 80%	3 x 3 @ 85%	3 x 3 @ 87.5%	3 x 3 @ 72.5%
Sets x Repetitions @ 1RM % BW = Body Weight **[a]Power clean for the Catch group / Clean pull for the Pull group** **[b]Mid-thigh power clean for the Catch group / Mid-thigh pull for the Pull group**				

Statistical Analyses

Normality of all data was determined via Shapiro-Wilk's test of normality, with all variables being normally distributed. Baseline measures were compared to determine within- and between-session reliability, as appropriate, using two-way random effects model intraclass correlation coefficients (ICC) and 95% confidence intervals. To assess the magnitude of the ICC, the values were interpreted as low (<0.30), moderate (0.30-0.49), high (0.50-0.69), very high (0.70-0.89), nearly perfect (0.90-0.99), and perfect (1.0) (28). Percentage coefficient of variation (%CV) was also calculated to determine the within session variability, with <10% classified as acceptable (12). In addition, t-tests were performed and Cohen's *d* effect sizes calculated to determine if there were any significant or meaningful differences between the baseline testing sessions.

A series of two-way repeated-measures analyses of variance (3 x 2; time x group), with Bonferroni post-hoc analysis, were performed to determine changes in the aforementioned kinetic and kinematic variables at each time point. A series of t-tests were performed to determine differences in the percentage change between phases (pre-mid, mid-post, pre-post) and between groups (Catch vs. Pull), for each variable. An *a priori* alpha level was set at $p \leq 0.05$. Further, the magnitude of any changes were determined via the calculation of effect sizes (Cohen's *d*), classified as trivial (≤0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), and very large (2.0 – 4.0) (27). All statistical analyses were performed using SPSS (Version 23. IBM, New York, NY).

Results

Between session 1RM PC performances were highly reliable (ICC = 0.997, 0.998) with a very low variability (CV = 0.23%, 0.13%) between sessions one (67.58 ± 23.06 kg; 0.94 ± 0.19 $kg.kg^{-1}$) and two (67.36 ± 22.59 kg; 0.93 ± 0.19 $kg.kg^{-1}$), for both absolute and relative performances, respectively.

Reliability of all jump variables demonstrated was very high to nearly perfect both within (ICC = 0.819-0.976) and between (ICC = 0.870-0.981) sessions, with low variability (CV = 0.27-5.96%) between trials. Furthermore, differences between sessions were trivial to small (*d* = 0.03-0.22) and not significant (Table 3).

Reliability of all IMTP variables demonstrated was very high to nearly perfect both within (ICC = 0.879-0.983) and nearly perfect (ICC = 0.966-0.981) between sessions, with acceptable variability (CV = 5.36-12.78%) between trials, with the variability reducing progressively with the time-point at which force was assessed. Furthermore, differences between sessions were trivial (*d* = 0.03-0.22) and non-significant ($p > 0.05$) (Table 4).

Table 3: Within and between session reliability (ICC (95% confidence intervals)) and variability (% coefficient of variation) of jump performance variables

Variable		Session 1	Session 2
SJ Height (m)	**Mean**	0.281	0.266
	SD	0.069	0.068
	Within Session ICC	0.944 (0.881-0.977)	0.962 (0.920-0.984)
	Between Session ICC	0.870 (0.661-0.951)	
	%CV	5.06	0.27
	d	0.22	
CMJ Height (m)	**Mean**	0.316	0.318
	SD	0.072	0.071
	Within Session ICC	0.954 (0.903-0.981)	0.981 (0.959-0.992)
	Between Session ICC	0.971 (0.925-0.989)	
	%CV	4.15	2.78
	d	0.03	
CMJ TTT (s)	**Mean**	0.73	0.72
	SD	0.08	0.10
	Within Session ICC	0.819 (0.652-0.921)	0.854 (0.710-0.937)
	Between Session ICC	0.893 (0.719-0.960)	
	%CV	3.06	2.86
	d	0.13	
CMJ RSImod	**Mean**	0.44	0.45
	SD	0.10	0.11
	Within Session ICC	0.906 (0.809-0.960)	0.940 (0.875-0.975)
	Between Session ICC	0.976 (0.933-0.991)	
	%CV	5.96	5.04
	d	0.12	

SJ: squat jump, CMJ: countermovement jump, TTT: time to take-off, RSImod: reactive strength index modified, SD: standard deviation, ICC: intraclass correlation coefficient, %CV: percentage coefficient of variation, *d*: Cohen’s *d* effect size

Table 4: Within and between session reliability (ICC (95% confidence intervals)) and variability (% coefficient of variation) of IMTP variables

Variable		**Session 1**	**Session 2**
F100 ms (N.kg^{-1})	**Mean**	20.32	20.35
	SD	6.23	5.20
	Within Session ICC	0.937 (0.869-0.974)	0.908 (0.798-0.963)
	Between Session ICC	0.980 (0.945-0.992)	
	%CV	5.50	12.78
	d	0.01	
F150 ms (N.kg^{-1})	**Mean**	25.18	25.01
	SD	7.92	6.15
	Within Session ICC	0.925 (0.845-0.969)	0.903 (0.786-0.961)
	Between Session ICC	0.966 (0.909-0.987)	
	%CV	6.28	11.62
	d	0.02	
F200 ms (N.kg^{-1})	**Mean**	28.73	28.28
	SD	8.72	6.76
	Within Session ICC	0.935 (0.865-0.973)	0.812 (0.64-0.918)
	Between Session ICC	0.967 (0.913-0.988)	
	%CV	5.82	8.94
	d	0.05	
F250 ms (N.kg^{-1})	**Mean**	30.32	30.06
	SD	9.05	7.40
	Within Session ICC	0.953 (0.902-0.981)	0.879 (0.761-0.949)
	Between Session ICC	0.978 (0.941-0.992)	
	%CV	5.36	6.19
	d	0.03	
Peak Force (N.kg^{-1})	**Mean**	38.19	38.91
	SD	12.24	11.70
	Within Session ICC	0.983 (0.964-0.993)	0.968 (0.930-0.987)
	Between Session ICC	0.981 (0.950-0.993)	
	%CV	3.44	4.29
	d	0.06	

SD: standard deviation, ICC: intraclass correlation coefficient, %CV: percentage coefficient of variation, *d*: Cohen’s *d* effect size

JUMP PERFORMANCES

Sphericity was assumed via Mauchley's test for all jump variables. The Catch group achieved significant (p <0.001; power = 0.794) improvements in SJ height across the duration of the intervention, with moderate and significant increase (12.6 ± 10.2%, p <0.001) from pre- to post-intervention. In contrast, post-hoc analysis demonstrated that changes were small and non-significant (p >0.05) between pre- and mid-intervention and mid- and post-intervention. There was only a trivial and non-significant increase (2.1 ± 11.8%, p >0.05) in SJ performance for the Pull group (Table 5). The Catch group exhibited greater improvements in SJ height pre- to mid-intervention (8.8 ± 13.1%), mid- to post-intervention (4.1 ± 7.9%), or pre- to post-intervention (12.6 ± 10.2%), compared to the Pull group (2.1 ± 11.8%, 1.9 ± 12.8%, 4.0 ± 17.6%, respectively), although these were small and not significantly different (d = 0.20-0.59; p >0.05) (Figure 3a).

The Catch group and Pull groups both achieved significant (p <0.001; power = 0.980; p = 0.04; power = 0.810, respectively) improvements in CMJ height across the duration of the intervention. The results of post-hoc analysis demonstrated that changes were small and non-significant (p >0.05) between pre- and mid-intervention and mid- to post-intervention for the Catch group, with a small yet significant (10.8 ± 12.3%, p = 0.007) increase from pre- to post-intervention. The Pull group achieved trivial and non-significant increases between pre- and mid-intervention and mid- to post-intervention, with small but significant increases (5.2 ± 9.2%, p = 0.04) pre- to post-intervention (Table 5). The Catch group exhibited greater improvements in CMJ height pre- to mid-intervention (5.4 ± 9.6%), mid- to post-intervention (5.1 ± 6.5%), or pre-to post-intervention (10.8 ± 12.3%), compared to the Pull group (3.7 ± 8.0%, 1.6 ± 7.2%, 5.2 ± 9.2%, respectively), although these were trivial to small and non-significant (d = 0.19-0.52; p >0.05) (Figure 3b).

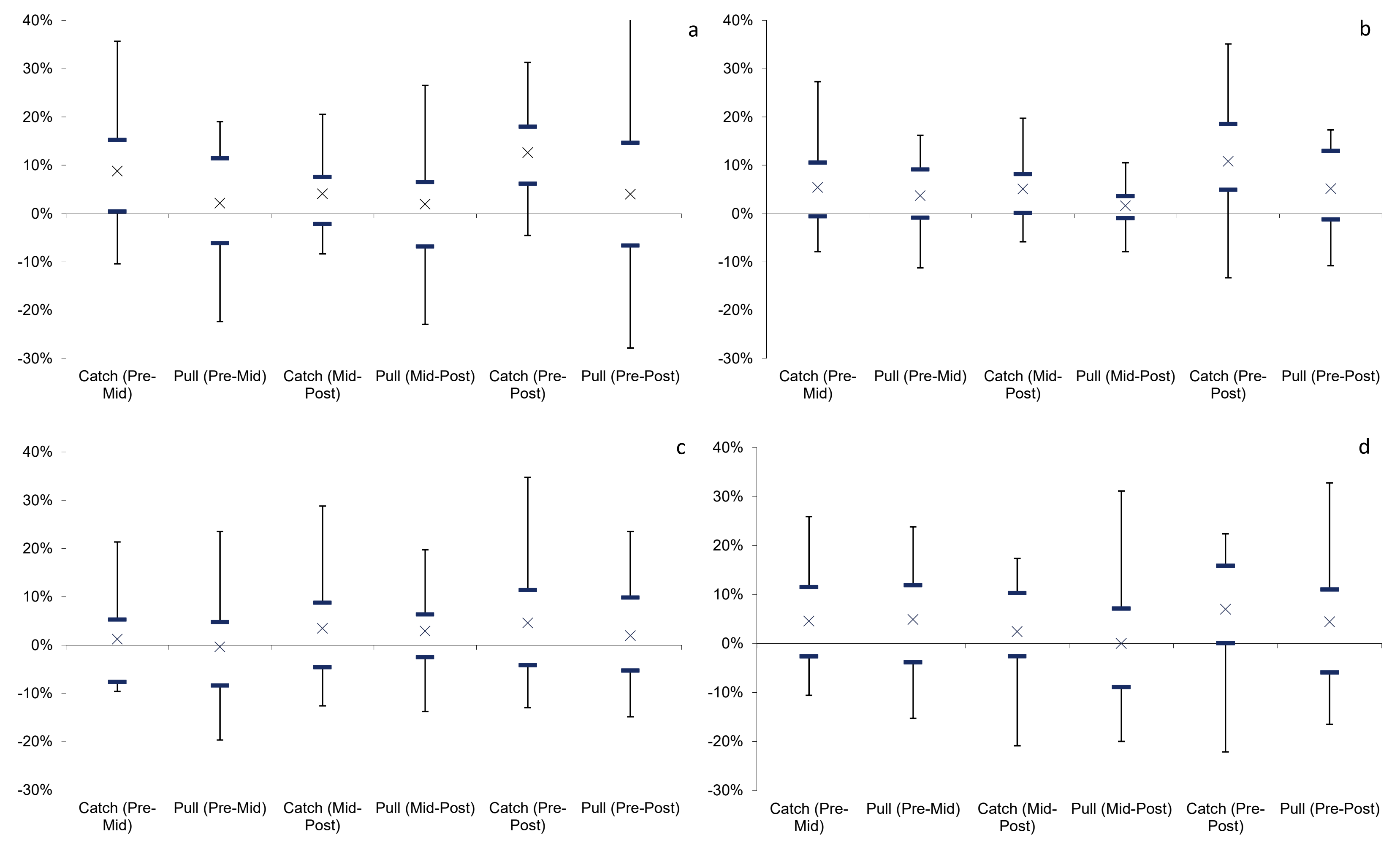


Figure 3: Comparison of percentage change in jump variables, across time points, for the Catch and Pull groups (SJ = squat jump; CMJ = countermovement jump; RSImod = reactive strength index modified)

For CMJ TTT there were trivial to small non-significant differences for both the Catch and Pull groups across all time points. There were trivial to small and non-significant differences (*p* >0.05) in percentage change TTT pre- to mid-intervention (1.2 ± 8.8%, -0.4 ± 12.2%, *d* = 0.15), mid- to post-intervention (3.5 ± 11.0%, 2.9 ± 10.6%, *d* = 0.06), and pre-post (4.6 ± 13.5%, 2.0 ± 12.0%, *d* = 0.20), between the Catch and Pull groups, respectively (Table 5, Figure 3c). There were only trivial to small changes in RSImod for both groups across all time points (Table 5), with trivial to small and non-significant differences (*p* >0.05) in percentage change in RSImod across phases (pre-mid: 4.6 ± 10.0%, 4.9 ± 10.1%, *d* = 0.03, mid-post: 2.4 ± 10.4%, 0.0 ± 13.7%, *d* = 0.20, pre-post: 7.0 ± 13.4%, 4.4 ± 14.1%, *d* = 0.19), between the Catch and Pull groups, respectively (Figure 3d).

Table 5: Changes in jump performance

Variable	**Group**	**Catch**			**Pull**		
		Pre	Mid	Post	Pre	Mid	Post
SJ Height (m)	**Mean**	0.283	0.305	0.317	0.283	0.287	0.289
	SD	0.052	0.048	0.053	0.061	0.057	0.055
	%CV	4.40	4.95	2.74	5.64	4.06	3.36
		0.44			0.05		
	d			0.24			0.05
			0.64*			0.10	
CMJ Height (m)	**Mean**	0.327	0.341	0.360	0.313	0.324	0.328
	SD	0.064	0.056	0.066	0.062	0.068	0.062
	%CV	4.05	3.12	2.78	3.29	3.92	2.36
		0.24			0.17		
	d			0.30			0.05
			0.50*			0.23*	
CMJ TTT (s)	**Mean**	0.71	0.72	0.74	0.76	0.75	0.77
	SD	0.09	0.10	0.09	0.09	0.09	0.10
	%CV	2.80	3.28	3.16	3.60	3.69	3.23
		0.07			0.08		
	d			0.21			0.19
			0.29			0.11	
RSImod	**Mean**	0.46	0.48	0.49	0.42	0.43	0.43
	SD	0.09	0.09	0.09	0.09	0.09	0.09
	%CV	6.73	6.24	6.69	6.10	5.89	4.00
		0.20			0.20		
	d			0.11			0.05
			0.29			0.16	

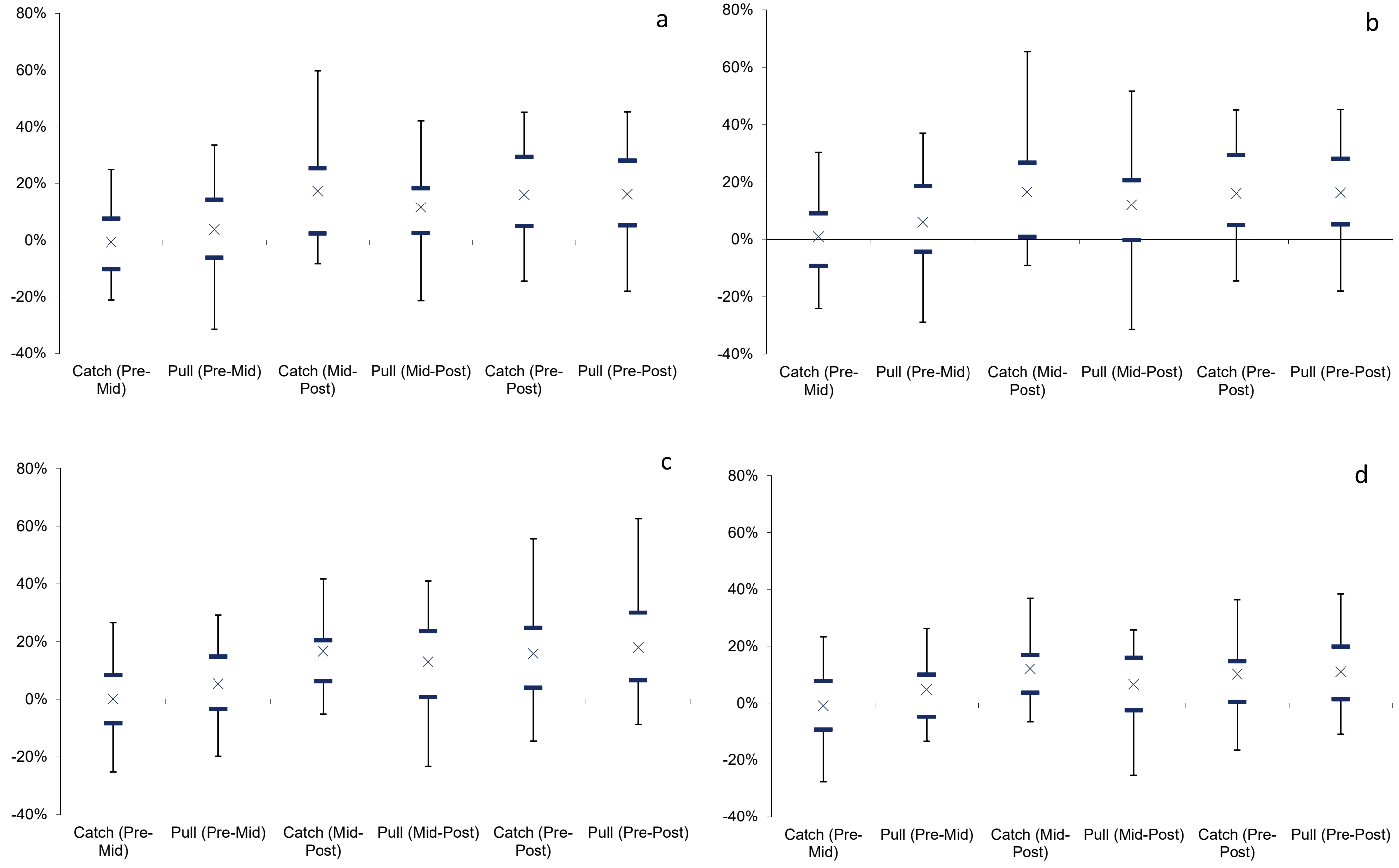
*=significant (*p* <0.05) increase pre to post intervention
SJ: squat jump, CMJ: countermovement jump, TTT: time to take-off, RSImod: reactive strength index modified, SD: standard deviation, %CV: percentage coefficient of variation, *d*: Cohen's *d* effect size

ISOMETRIC MID-THIGH PULL

Sphericity was assumed via Mauchley's test for all IMTP variables. The Catch and Pull groups both demonstrated significant (*p* <0.001; power = 0.931) increases in F100. Both groups showed trivial non-significant (*p* >0.05) changes pre- to mid-intervention, with small significant

(Catch: 17.3 ± 22.0%, *p* = 0.03 Pull: 11.5 ± 21.4%, *p* = 0.04) increases mid- to post-intervention and pre- to post-intervention (Catch: 14.9 ± 17.2%, *p* = 0.011 Pull: 15.5 ± 16.0%, *p* = 0.03) (Table 6). Trivial to small and non-significant differences (*d* = 0.08-0.23, p>0.05) in percentage change F100 across phases (pre-mid: -0.7 ± 13.5%, 3.7 ± 15.9%, mid-post: 17.3 ± 22.0%, 11.5 ± 21.4%, pre-post: 14.9 ± 17.2%, 13.5 ± 16.0%), were evident between the Catch and Pull groups, respectively (Figure 4a).

Both groups demonstrated significant (*p* = 0.005; power = 0.855) increases in F150, with both groups showing trivial to small non-significant (*p* >0.05) changes pre- to mid-intervention, with the Catch group demonstrating small significant (16.5 ± 20.4%, *p* = 0.022) increases mid- to post-intervention and the Pull group demonstrating small but non-significant (12.0 ± 22.9%, *p* >0.05) increases mid- to post-intervention. Both groups demonstrated moderate and significant increases (Catch: 16.0 ± 17.6%, *p* = 0.003 Pull: 16.2 ± 18.4%, *p* = 0.01) in F150 pre- to post-intervention (Table 6). Trivial to small and non-significant differences (*d* = 0.01-0.31, p >0.05) in percentage change F150 across phases (pre-mid: 0.9 ± 14.9%, 5.9 ± 17.5%, mid-post: 16.5 ± 17.6%, 12.0 ± 22.9%, pre-post: 16.0 ± 17.6%, 16.2 ± 18.4%), were evident between the Catch and Pull groups, respectively (Figure 4b).



a = force at 100 ms; b = force at 150 ms; c = force at 200 ms; d = force at 250 ms

Figure 4: Comparison of percentage change in isometric mid-thigh pull time specific force variables, across time points, for the Catch and Pull groups

Both groups demonstrated significant (*p* = 0.007; power = 0.842) increases in F200. Both groups showed trivial to small non-significant (*p* >0.05) changes pre- to mid-intervention, with small non-significant (Catch: 16.6 ± 17.9%, Pull: 12.9 ± 16.8%, *p* >0.05) increases mid- to post-intervention and small, significant increases pre- to post-intervention (Catch: 15.8 ± 17.6%, *p* = 0.017 Pull: 17.9 ± 18.3%, *p* = 0.02) (Table 6). The Pull group demonstrated small yet significantly greater (*d* = 0.38, *p* = 0.002) increases in F200 pre- to mid-intervention (5.3 ± 14.0%) compared to the Catch group (0.1 ± 13.2%). There were, however, only trivial to small and non-significant differences (*d* = 0.12-0.21, *p* >0.05) in percentage change F200 mid- to post-intervention (16.6 ± 17.9%, 12.9 ± 16.8%) or pre- to post-intervention (15.8 ± 17.6%, 17.9 ± 18.3%), between the Catch and Pull groups, respectively (Figure 4c).

Both groups demonstrated significant (*p* = 0.007; power = 0.834) increases in F250, with the Catch group showing a trivial non-significant (*p* >0.05) decrease pre- to mid-intervention, while the Pull group showed a small but non-significant increase (p >0.05). The Catch croup demonstrated a small significant (12.0 ± 16.6%, *p* = 0.045) increase mid- to post-intervention and small significant increase pre- to post-intervention (10.0 ± 16.1%, *p* = 0.025), while the Pull group demonstrated a small significant (6.5 ± 13.4%, *p* = 0.045) increase mid- to post-intervention and small significant increase pre- to post-intervention (10.9 ± 14.4%, *p* = 0.025) (Table 6). Trivial to small and non-significant differences (*d* = 0.06-0.47, *p* >0.05) in percentage change F250 were evident, across phases (pre-mid: -1.0 ± 12.5%, 4.7 ± 11.7%, mid-post: 12.0 ± 16.6%, 6.5 ± 13.4%, pre-post: 10.0 ± 16.1%, 10.9 ± 14.4%), between the Catch and Pull groups, respectively (Figure 4d).

Both groups demonstrated significant (*p* = 0.001; power = 0.869) and progressive increases in relative PF, with the Catch group showing a trivial non-significant (*p* >0.05) increase pre- to mid-intervention, while the Pull group showed a small but significant increase (*p* = 0.017). In contrast the Catch group demonstrated a small significant (8.4 ± 10.8%, *p* = 0.028) increase mid- to post-intervention while the Pull group demonstrated a trivial non-significant (*p* >0.05) increase in relative PF. Both groups demonstrated small significant increases (Catch: 13.7 ± 18.7%, *p* = 0.021; Pull: 9.7 ± 16.3%, *p* = 0.045) in relative PF pre- to post-intervention (Table 6). The Catch group demonstrated a moderately and significantly greater (*d* = 0.84, *p* = 0.014) increase in PF mid- to post-intervention (8.4 ± 10.8%) compared to the Pull group (0.2 ± 8.5%). There were, however, only small and non-significant differences (*d* = 0.23-0.45, *p*>0.05) in percentage change PF pre- to mid-intervention (4.6 ± 9.6%, 9.8 ± 13.1%) or pre- to post-intervention (13.7 ± 18.7%, 9.7 ± 16.3%), between the Catch and Pull groups, respectively (Figure 5a).

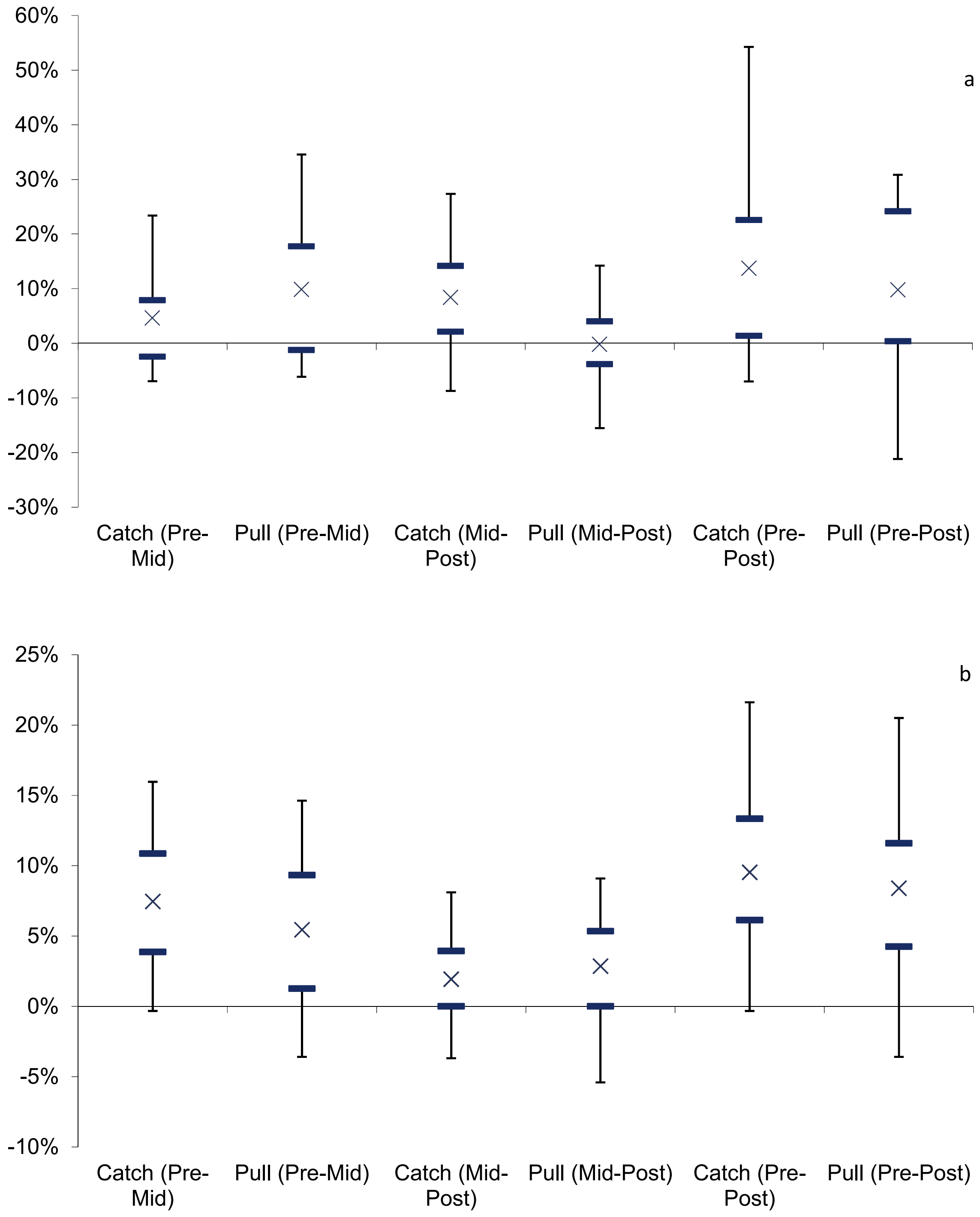
Table 6: Changes in isometric mid-thigh pull performance

	Group	Catch			Pull		
		Pre	Mid	Post	Pre	Mid	Post
F100 ms (N.kg^{-1})	**Mean**	20.00	19.95	22.92	17.93	18.49	20.14
	SD	5.07	4.52	5.94	3.74	4.06	4.11
	%CV	5.48	8.68	7.76	6.68	9.30	8.20
		0.01			0.14		
	d			0.46*			0.40*
			0.45*			0.56*	
F150 ms (N.kg^{-1})	**Mean**	24.76	25.11	28.67	22.07	23.28	25.21
	SD	6.23	5.49	6.61	5.44	6.22	5.37
	%CV	5.66	8.79	5.83	9.26	10.84	8.75
		0.06			0.21		
	d			0.59*			0.33
			0.61*			0.58*	
F200 ms (N.kg^{-1})	**Mean**	28.20	28.22	31.36	25.42	26.74	28.54
	SD	6.22	5.41	6.68	5.51	6.47	5.95
	%CV	4.75	7.76	4.04	7.56	9.52	8.95
		0.03			0.23		
	d			0.52*			0.29
			0.49*			0.54*	
F250 ms (N.kg^{-1})	**Mean**	29.72	29.27	32.47	26.90	28.16	29.67
	SD	6.30	5.31	6.31	5.45	6.36	6.53
	%CV	4.18	6.99	2.89	5.75	7.32	8.54
		0.00			0.21		
	d			0.47*			0.23
			0.44*			0.46*	
Peak Force (N.kg^{-1})	**Mean**	36.83	38.18	41.20	34.69	37.94	37.98
	SD	8.00	7.02	7.51	5.66	6.67	7.95
	%CV	3.72	3.21	3.74	3.58	2.99	3.06
		0.18			0.53*		
	d			0.42*			0.01
			0.56*			0.48*	

*= significant (*p* <0.05) increase

POWER CLEAN

For the relative PC, sphericity was assumed via Mauchley's test, with both groups demonstrating significant (*p* <0.001; power = 1.00) increases in relative PC 1RM. The Catch group showed small significant (*d* = 0.44, *p* = 0.01) increases pre- (0.93 ± 0.15 kg.kg^{-1}) to mid-intervention (0.99 ± 0.12 kg.kg^{-1}), with trivial non-significant (*d* = 0.15, *p* = 0.14) increases mid- to post-intervention (1.01 ± 0.14 kg.kg^{-1}), resulting in a small significant (*d* = 0.55, *p* <0.001) increase pre- to post-intervention (Figure 5b). The Pull group showed small significant (*d* = 0.23, *p* = 0.001) increases pre- (0.91 ± 0.18 kg.kg^{-1}) to mid-intervention (0.95 ± 0.17 kg.kg^{-1}), with trivial, yet significant (*d* = 0.17, *p* = 0.015) increases mid- to post-intervention (0.98 ± 0.18 kg.kg^{-1}), resulting in a small significant (*d* = 0.39, *p* <0.001) increase pre- to post-intervention. There were small non-significant differences (p >0.05) in percentage change in relative PC performance pre- to mid-intervention (7.4 ± 5.0%, 5.4 ± 5.4%, *d* = 0.38) mid- to post-intervention (1.9 ± 0.8%, 2.9 ± 4.1%, *d* = 0.34) and only trivial differences pre- to post intervention (9.5 ± 6.2%, 8.4 ± 6.1%, *d* = 0.18) between the Catch and Pull groups, respectively (Figure 5b).



a = Isometric Mid-Thigh Pull Peak Force; b = Relative 1RM Power Clean

Figure 5: Comparison of percentage change in isometric mid-thigh pull peak force and relative one repetition maximum power clean performances, across time points, for the Catch and Pull groups

There were no significant (*p* >0.05) changes in body mass for either the Catch (Pre 71.14 ± 11.79 kg; Mid 71.03 ± 11.48 kg; Post 70.95 ± 11.07 kg) or the Pull group (Pre 66.43 ± 10.13 kg; Mid 66.64 ± 9.97 kg; Post 66.68 ± 10.11 kg) across the duration of the intervention.

Discussion

This is the first study to compare the effects of including or excluding the catch phase of PC derivatives, on training adaptations, in terms of force-time characteristics during dynamic and isometric tasks. Both groups demonstrated improvements in CMJ height, IMTP variables and PC performance pre- to post-intervention, as hypothesized. In contrast to the hypotheses, the Catch group increased SJ height, whereas there was no change in the Pull group. Also in contrast to the hypotheses, there was no difference in percentage change, in any variables, between groups, which may be attributed to the comparable training stimulus during the propulsion phase of each exercise along with the identical volume load.

The Catch group achieved moderate improvements in SJ height (12.6%) across the duration of the intervention, whereas the Pull group only demonstrated trivial increases (2.1%). It is possible that this difference is due to the requirement to rapidly produce force to arrest motion during the Catch, whereas a greater time is available to decelerate the barbell and the system center of mass during the pulling derivatives. The Catch group also exhibited greater improvements in CMJ height (10.8%), compared to the Pull group (5.2%) across the duration of the study, although improvements in both groups were small and significant, the difference in improvements between groups was small yet not significant. To achieve the CMJ heights, there were no meaningful or significant changes in TTT, implying that an increase in jump height must have been a result of an increase in force applied, resulting in an increased impulse and therefore velocity at take-off. The lack of change in TTT, combined with the increase in jump height, resulted in favorable, yet small and non-significant increases in RSImod for both the Catch (7.0%) and Pull (4.4%) groups (Figure 3). The small magnitudes of increases in jump performance are in line with previous findings, reported after a 10-week training intervention comparing the training effects of hang high pulls and hexagonal barbell jump squats, in collegiate swimmers (37). In addition, the transfer of weightlifting style training, has recently been reported to result in only small changes in jump performance over relatively short training periods (26), as observed here. In contrast however, traditional resistance training combined with weightlifting derivatives has been shown to enhance longitudinal maximal strength and jump performance (30).

Both groups demonstrated trivial to small and non-significant increases in time-specific force values during the initial four weeks (pre- to mid- intervention), with small to moderate and significant increases in the final four weeks (mid- to post-intervention). This resulted in small to moderate increases in F100 (14.9%; 15.5%), F150 (16.0%; 16.2%), F200 (15.8%: 17.9%) and F250 (15.8%; 17.9%) for the Catch and Pull groups respectively. The greater increases in time-specific force production, during the second four weeks of training, may be due the higher intensities used, resulting in the subjects having to ensure a maximal intent and rapid force production to adequately accelerate the barbell. The Pull group consistently demonstrated a greater percentage change in all time-specific forces although these differences were small and non-significant (Figure 4). These observations are similar to those previously reported by Oranchuk et al. (37) who also reported no meaningful differences in relative PF and time-specific force variables, after 10-weeks of hang high pull versus hexagonal barbell jump squat training.

In contrast to the changes in IMTP time-specific forces, PF increased to the greatest extent during the first four weeks (pre-mid), with the Catch group demonstrating greater improvements (13.7%) compared to the Pull group (9.7%), although the differences between groups were trivial. Interestingly, PC performances exhibited similar trends, with the greatest improvements occurring during the first 4 weeks, and the Catch group demonstrating slightly greater improvements (9.5%) compared to the Pull group (8.4%). It is likely that similarity in these adaptations are due to the strong relationships between IMTP PF and PC performance previously reported (33). These greater increases in PC performance, during the first four weeks, may be due to the slightly greater volume of power clean derivatives performed during this phase, compared to the second phase. The magnitude of the changes in PC performance is also greater than the smallest worthwhile change previously reported to indicate meaningful changes for the PC (9, 14) and the IMTP (7, 14).

Both the groups improved their 1RM PC over the course of the training interventions. Interestingly, the Pull group were able to improve their 1RM PC to a similar extent compared to the Catch group despite not training with the catch phase. This is important to note considering not all individuals are able to adequately perform the catch phase due to poor technique, inflexibility or previous or current injury. Thus, training with pulling derivatives may provide an effective training stimulus for improving maximal dynamic strength, which is comparable to the use of weightlifting catching derivatives. As mentioned above, each training group exhibited small, significant training effects over the course of the study, with only a trivial difference, in the percentage increase in performance, between groups. From a specificity standpoint, this finding is unsurprising given that this group performed submaximal training with the PC exercise. These improvements in PC (9, 14, 17) and IMTP (7, 14) performance were also greater than the between session smallest detectable differences previously reported.

A potential limitation to the current study was the use of identical loading procedures between the Catch and Pull groups. In an effort to equalize training volume, each group was prescribed the same relative intensity and volume load, during each training block. While this may make sense from a research standpoint, the pulling derivatives implemented within the current study (e.g. clean grip mid-thigh pull and pull from the floor) are typically implemented using loads in excess of an athlete's 1RM PC (i.e. > 100%) (8, 10, 22, 31), while additional repetitions may be able to be performed at submaximal loads, compared to catch variations. Thus, the loads implemented for these exercises may not have provided an adequate load or volume stimulus to the Pull group, which may have prevented them from displaying greater training benefits compared to the Catch group. Given that weightlifting pulling derivatives may produce greater force and velocity characteristics, dependent on the load used (43), researchers may consider investigating the training effects of weightlifting pulling derivatives that use loads which emphasize either a force or velocity overload stimulus, as described by Suchomel et al., (43), compared to training with weightlifting catching derivatives.

It is also worth noting, that as this was an in-season training intervention, with relatively low training volumes, to minimize any potentially negative impact on the athletes' competitive performances, a future study conducted in pre-season, is recommended, where higher training volume loads and, or relative intensities (based on 1RM PC performance) can be incorporated.

Practical Application

The results of this study indicate that training with either weightlifting catching or weightlifting pulling derivatives improved the athletes' performance across a spectrum of variables. It is important to note, however that trivial to small differences existed between training groups when examining every variable, indicating that catching and pulling derivatives may provide a similar training stimulus when the same relative intensity (based on 1RM PC) and volume loads are implemented during an in-season training program. Thus, both catching and pulling derivatives may provide an effective training stimulus when training to improve strength-power characteristics. It is suggested, therefore, that strength and conditioning coaches and athletes should appropriately periodize the use of weightlifting derivatives, and that pulling and catching derivatives can be used interchangeable to achieve similar goals, when performed using the same relative intensity and volume loads.

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Figure and Table Legends:

Figure 1: Summary of testing schedule

Figure 2: Testing sequence (SJ: squat jump, CMJ: countermovement jump, IMTP: Isometric Mid-Thigh Pull)

Figure 3: Comparison of percentage change in jump variables across time points for the Catch and Pull groups

Figure 4: Comparison of percentage change in isometric mid-thigh pull time specific force variables, across time points, for the Catch and Pull groups

Figure 5: Comparison of percentage change in isometric mid-thigh pull peak force and relative one repetition maximum power clean across time points for the Catch and Pull groups

Table 1: Training sessions, weeks 1-4

Table 2: Training sessions, weeks 6-9

Table 3: Within and between session reliability (ICC (95% confidence intervals)) and variability (% coefficient of variation) of jump performance variables

Table 4: Within and between session reliability (ICC (95% confidence intervals)) and variability (% coefficient of variation) of IMTP variables

Table 5: Changes in jump performance

Table 6: Changes in isometric mid-thigh pull performance