



University of
Salford
MANCHESTER

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

Comfort, P, Dos'Santos, T, Thomas, C, McMahon, JJ and Suchomel, TJ

<http://dx.doi.org/10.1519/JSC.0000000000002656>

Title	An investigation into the effects of excluding the catch phase of the power clean on force-time characteristics during isometric and dynamic tasks
Authors	Comfort, P, Dos'Santos, T, Thomas, C, McMahon, JJ and Suchomel, TJ
Publication title	Journal of Strength and Conditioning Research
Publisher	Wolters Kluwer
Type	Article
USIR URL	This version is available at: http://usir.salford.ac.uk/id/eprint/47329/
Published Date	2018

USIR is a digital collection of the research output of the University of Salford. Where copyright permits, full text material held in the repository is made freely available online and can be read, downloaded and copied for non-commercial private study or research purposes. Please check the manuscript for any further copyright restrictions.

For more information, including our policy and submission procedure, please contact the Repository Team at: library-research@salford.ac.uk.

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

3

4 Paul Comfort^{1#}, Thomas Dos'Santos¹, Christopher Thomas^{1,2}, John. J. McMahon¹ & Timothy.
5 J. Suchomel³.

6 Author affiliations: ¹ Directorate of Sport, Exercise and Physiotherapy, University of Salford,
7 Frederick Road, Salford, Greater Manchester. UK. ² University of South Wales. Pontypridd.
8 Cardiff, Wales. UK. ³ Department of Human Movement Sciences, Carroll University,
9 Waukesha, WI, USA

10 # Corresponding author: p.comfort@salford.ac.uk

11

12

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

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

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

32

33

34 **Abstract**

35 The aims of this study were to compare the effects of the exclusion or inclusion of the catch
36 phase, during power clean (PC) derivatives, on force-time characteristics during isometric and
37 dynamic tasks, after two, four-week mesocycles of resistance training. Two strength matched
38 groups, completed the twice weekly training sessions, either including the catch phase of the
39 PC derivatives (Catch: $n = 16$; age 19.3 ± 2.1 years; height 1.79 ± 0.08 m; body mass 71.14
40 ± 11.79 kg; PC one repetition maximum [1-RM] 0.93 ± 0.15 kg.kg⁻¹) or excluding the catch
41 phase (Pull: $n = 18$; age 19.8 ± 2.5 years; height 1.73 ± 0.10 m; body mass 66.43 ± 10.13 kg;
42 PC 1RM 0.91 ± 0.18 kg.kg⁻¹). The Catch and Pull groups both demonstrated significant ($p \leq$
43 0.007 , power ≥ 0.834) and meaningful improvements in countermovement jump (CMJ) height
44 ($10.8 \pm 12.3\%$, $5.2 \pm 9.2\%$), isometric mid-thigh pull (IMTP) performance (force [F]100: $14.9 \pm$
45 17.2% , $15.5 \pm 16.0\%$, F150: $16.0 \pm 17.6\%$, $16.2 \pm 18.4\%$, F200: $15.8 \pm 17.6\%$, $17.9 \pm 18.3\%$,
46 F250: $10.0 \pm 16.1\%$, $10.9 \pm 14.4\%$, PF: $13.7 \pm 18.7\%$, $9.7 \pm 16.3\%$) and PC 1RM ($9.5 \pm 6.2\%$,
47 $8.4 \pm 6.1\%$), pre- to post-intervention, respectively. In contrast to the hypotheses, there were
48 no meaningful or significant differences in percentage change, for any variables, between
49 groups. This study clearly demonstrates that neither the inclusion nor exclusion of the catch
50 phase of the PC derivatives result in any preferential adaptations over two 4-week, in-season
51 strength and power, mesocycles.

52

53 **Key Words:** Countermovement Jump; Weightlifting; Performance; Training

54

55

56

57 **INTRODUCTION**

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

65 Observations of weightlifting performances have established that the second pull phase of the
66 clean and snatch elicits the greatest peak power, compared to the other phases of the lifts
67 (18), albeit using barbell velocity and inverse dynamics to assess peak power applied to it.
68 Furthermore, peak force (PF) and rate of force development (RFD) have also been shown to
69 occur during the second pull phase of the clean and clean pull (16, 39). More recently, the

70 mid-thigh power clean (PC) and mid-thigh pull have been shown to result in significantly
71 greater ($p < 0.001$) PF, peak RFD (5) and peak power applied to the lifter plus bar system (6)
72 when compared to the hang power clean and PC. Moreover, no significant ($p > 0.05$)
73 differences were observed between these lifts irrespective of the inclusion or exclusion of the
74 catch phase (5, 6). In addition, Suchomel et al. (47) reported that the jump shrug, (similar to
75 the mid-thigh pull but initiated with a countermovement and the athlete actually leaves the
76 ground) resulted in significantly ($p < 0.05$) greater PF, peak velocity, and peak power
77 compared to the hang power clean and hang high pull across all loads (30, 45, 65, 80% one
78 repetition maximum [1RM] hang clean), indicating that the removal of a catch phase during a
79 PC derivative is not detrimental to the peak power achieved. Similarly, additional studies by
80 Suchomel et al. (45, 46) also reported greater relative PF, power, impulse, work, and peak
81 RFD in the jump shrug compared to the hang power clean and hang high pull across loads
82 (30, 45, 65, 80% 1RM hang clean). More recently, researchers have examined these
83 differences at the joint-level, with Kipp et al. (32) indicating that the jump shrug produces
84 greater magnitudes of joint work and power compared to the hang power clean across several
85 loads.

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

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

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

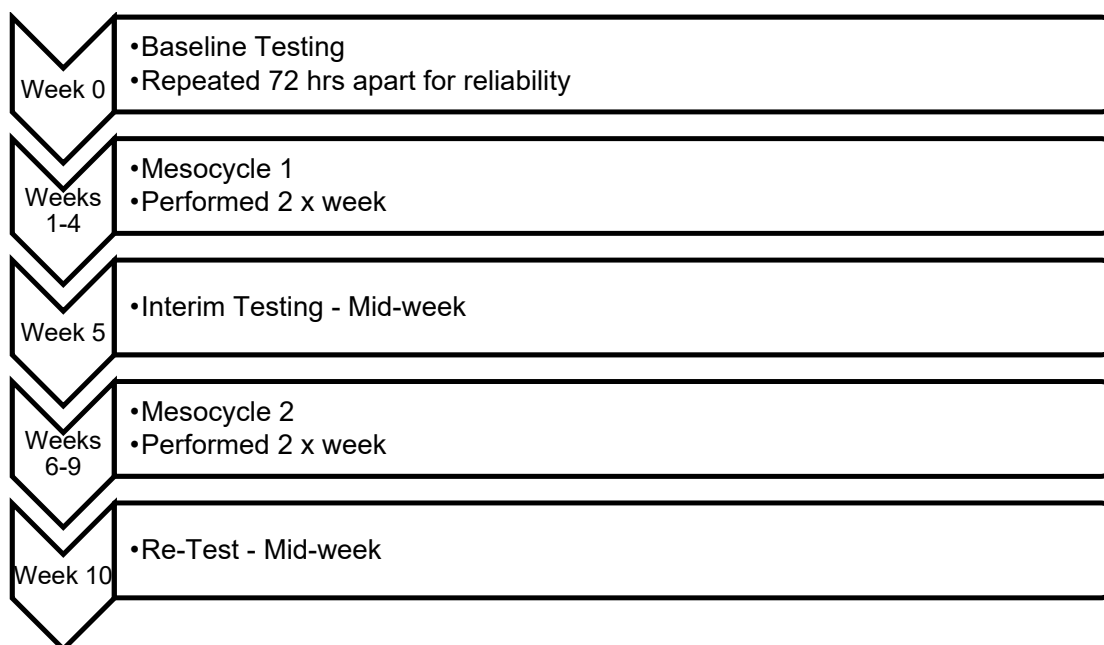
116 **METHODS**

117

118 **EXPERIMENTAL APPROACH TO THE PROBLEM**

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

127



128

129 Figure 1: Summary of testing schedule

130

131 **Subjects**

132 Professional youth soccer players (n = 18) and collegiate athletes (n = 26), from the United
 133 Kingdom, initially volunteered to participate in this investigation. All subjects were experienced
 134 (training age: 3.1 ± 1.2 years) and competent in each of the lifts performed in the interventions,
 135 as determined by a certified strength and conditioning specialist. After baseline testing
 136 subjects were divided into the two groups by matching relative 1RM PC performances, with
 137 an equal number of athletes from each sport in both groups. Due to injury from competition
 138 and or illness across the duration of the intervention the number of subjects to complete the
 139 entire study reduced to 11 professional male soccer players and 23 collegiate athletes who
 140 participated in a variety of sports (BMX, rowing, field hockey). Due to drop out, the final mean
 141 1RM PC performance for the groups differed slightly; Catch (n = 16, 12 male, 4 female [5
 142 soccer, 3 BMX, 6 rowing, 2 field hockey]; age 19.3 ± 2.1 years; height 1.79 ± 0.08 m; body
 143 mass 71.14 ± 11.79 kg; 1RM PC 0.93 ± 0.15 kg.kg⁻¹) Pull (n = 18, 14 male, 4 female [6 soccer,

144 2 BMX, 7 rowing, 2 field hockey]; age 19.8 ± 2.5 years; height 1.73 ± 0.10 m; body mass 66.43
 145 ± 10.13 kg; 1RM PC 0.91 ± 0.18 kg.kg⁻¹). A minimum of 11 subjects per groups was required
 146 for an *a priori* power ≥ 0.80 , at an alpha level of $p \leq 0.05$, with post hoc power presented in the
 147 results section. This study was approved by the institutional review board, in accordance with
 148 the declaration of Helsinki. All subjects provided written informed consent, or parental assent
 149 as appropriate.

150

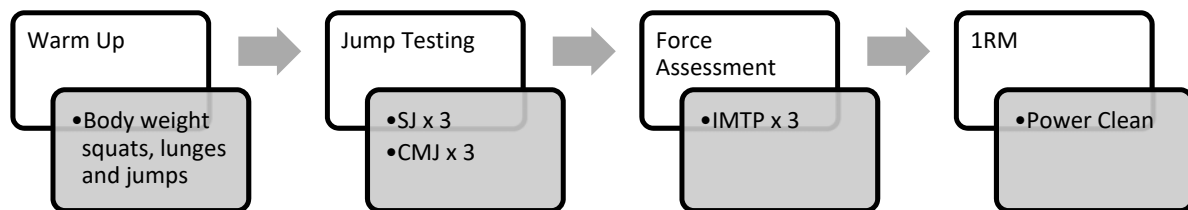
151 PROCEDURES

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

161

162

163



164

165 Figure 2: Testing sequence

166

167

168 **Jump Performances**

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

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

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

185

186 ***Isometric Mid-thigh Pull Assessment***

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

200

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

211

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

217

218 ***One Repetition Maximum Power Clean***

219 The 1RM PC performances were determined based on the standardized NSCA protocol (1).
220 Briefly, subjects performed warm-up PC sets using sub maximal loads prior to performing a
221 maximal attempt, with a progressive increase in loading during the maximal attempts
222 (International Weightlifting Federation, accredited bars and plates were used throughout). Any

223 power clean repetition caught with the top of the subject's thighs below parallel was ruled as
224 an unsuccessful attempt.

225

226 **DATA ANALYSIS:**

227 *Kinetic and Kinematic Variables*

228 Raw force-time data for both the jumps and the IMTP were analyzed in Microsoft Excel (Excel
229 2016, Microsoft, Washington, USA). Jump height was calculated from velocity of center of
230 mass at take-off, for both the SJ and CMJ (35). Center of mass velocity was determined by
231 dividing vertical force data (minus body weight) by body mass and then integrating the product
232 using the trapezoid rule. The start of the CMJ was identified in line with current
233 recommendations (38). Take-off was identified when vertical force decreased below five times
234 the standard deviation of the force during the flight phase (residual force) (34).

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

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

244

245 **INTERVENTION**

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

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

264

265

266

267 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				

268

269 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				

270

271 **Statistical Analyses**

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

282 A series of two-way repeated-measures analyses of variance (3 x 2; time x group), with
283 Bonferroni post-hoc analysis, were performed to determine changes in the aforementioned
284 kinetic and kinematic variables at each time point. A series of t-tests were performed to
285 determine differences in the percentage change between phases (pre-mid, mid-post, pre-post)
286 and between groups (Catch vs. Pull), for each variable. An *a priori* alpha level was set at p
287 ≤ 0.05 . Further, the magnitude of any changes were determined via the calculation of effect
288 sizes (Cohen's d), classified as trivial (≤ 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19),
289 large (1.20 – 1.99), and very large (2.0 – 4.0) (27). All statistical analyses were performed
290 using SPSS (Version 23. IBM, New York, NY).

291

292 **Results**

293 Between session 1RM PC performances were highly reliable (ICC = 0.997, 0.998) with a very
294 low variability (CV = 0.23%, 0.13%) between sessions one (67.58 ± 23.06 kg; 0.94 ± 0.19
295 $\text{kg}\cdot\text{kg}^{-1}$) and two (67.36 ± 22.59 kg; 0.93 ± 0.19 $\text{kg}\cdot\text{kg}^{-1}$), for both absolute and relative
296 performances, respectively.

297 Reliability of all jump variables demonstrated was very high to nearly perfect both within (ICC
298 = 0.819-0.976) and between (ICC = 0.870-0.981) sessions, with low variability (CV = 0.27-
299 5.96%) between trials. Furthermore, differences between sessions were trivial to small ($d =$
300 0.03-0.22) and not significant (Table 3).

301 Reliability of all IMTP variables demonstrated was very high to nearly perfect both within (ICC
302 = 0.879-0.983) and nearly perfect (ICC = 0.966-0.981) between sessions, with acceptable
303 variability (CV = 5.36-12.78%) between trials, with the variability reducing progressively with
304 the time-point at which force was assessed. Furthermore, differences between sessions were
305 trivial ($d = 0.03$ -0.22) and non-significant ($p > 0.05$) (Table 4).

306

307

308

309

310

311

312

313

314

315

316

317 Table 3: Within and between session reliability (ICC (95% confidence intervals)) and variability
 318 (% 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	0.944	0.962
	Session ICC	(0.881-0.977)	(0.920-0.984)
	Between	0.870	
	Session ICC	(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	0.954	0.981
	Session ICC	(0.903-0.981)	(0.959-0.992)
	Between	0.971	
	Session ICC	(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	0.819	0.854
	Session ICC	(0.652-0.921)	(0.710-0.937)
	Between	0.893	
	Session ICC	(0.719-0.960)	
	%CV	3.06	2.86
	d	0.13	
CMJ RSI_{mod}	Mean	0.44	0.45
	SD	0.10	0.11
	Within	0.906	0.940
	Session ICC	(0.809-0.960)	(0.875-0.975)
	Between	0.976	
	Session ICC	(0.933-0.991)	
	%CV	5.96	5.04
	d	0.12	

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

319

320

321

322

323

324 Table 4: Within and between session reliability (ICC (95% confidence intervals)) and variability
 325 (% 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	0.937	0.908
	Session ICC	(0.869-0.974)	(0.798-0.963)
	Between	0.980	
	Session ICC	(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	0.925	0.903
	Session ICC	(0.845-0.969)	(0.786-0.961)
	Between	0.966	
	Session ICC	(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	0.935	0.812
	Session ICC	(0.865-0.973)	(0.64-0.918)
	Between	0.967	
	Session ICC	(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	0.953	0.879
	Session ICC	(0.902-0.981)	(0.761-0.949)
	Between	0.978	
	Session ICC	(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	0.983	0.968
	Session ICC	(0.964-0.993)	(0.930-0.987)
	Between	0.981	
	Session ICC	(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

326

327

328 JUMP PERFORMANCES

329 Sphericity was assumed via Mauchley's test for all jump variables. The Catch group achieved
330 significant ($p < 0.001$; power = 0.794) improvements in SJ height across the duration of the
331 intervention, with moderate and significant increase ($12.6 \pm 10.2\%$, $p < 0.001$) from pre- to
332 post-intervention. In contrast, post-hoc analysis demonstrated that changes were small and
333 non-significant ($p > 0.05$) between pre- and mid-intervention and mid- and post-intervention.
334 There was only a trivial and non-significant increase ($2.1 \pm 11.8\%$, $p > 0.05$) in SJ performance
335 for the Pull group (Table 5). The Catch group exhibited greater improvements in SJ height pre-
336 to mid-intervention ($8.8 \pm 13.1\%$), mid- to post-intervention ($4.1 \pm 7.9\%$), or pre- to post-
337 intervention ($12.6 \pm 10.2\%$), compared to the Pull group ($2.1 \pm 11.8\%$, $1.9 \pm 12.8\%$, $4.0 \pm$
338 17.6% , respectively), although these were small and not significantly different ($d = 0.20-0.59$;
339 $p > 0.05$) (Figure 3a).

340 The Catch group and Pull groups both achieved significant ($p < 0.001$; power = 0.980; $p = 0.04$;
341 power = 0.810, respectively) improvements in CMJ height across the duration of the
342 intervention. The results of post-hoc analysis demonstrated that changes were small and non-
343 significant ($p > 0.05$) between pre- and mid-intervention and mid- to post-intervention for the
344 Catch group, with a small yet significant ($10.8 \pm 12.3\%$, $p = 0.007$) increase from pre- to post-
345 intervention. The Pull group achieved trivial and non-significant increases between pre- and
346 mid-intervention and mid- to post-intervention, with small but significant increases ($5.2 \pm 9.2\%$,
347 $p = 0.04$) pre- to post-intervention (Table 5). The Catch group exhibited greater improvements
348 in CMJ height pre- to mid-intervention ($5.4 \pm 9.6\%$), mid- to post-intervention ($5.1 \pm 6.5\%$), or
349 pre-to post-intervention ($10.8 \pm 12.3\%$), compared to the Pull group ($3.7 \pm 8.0\%$, $1.6 \pm 7.2\%$,
350 $5.2 \pm 9.2\%$, respectively), although these were trivial to small and non-significant ($d = 0.19-$
351 0.52 ; $p > 0.05$) (Figure 3b).

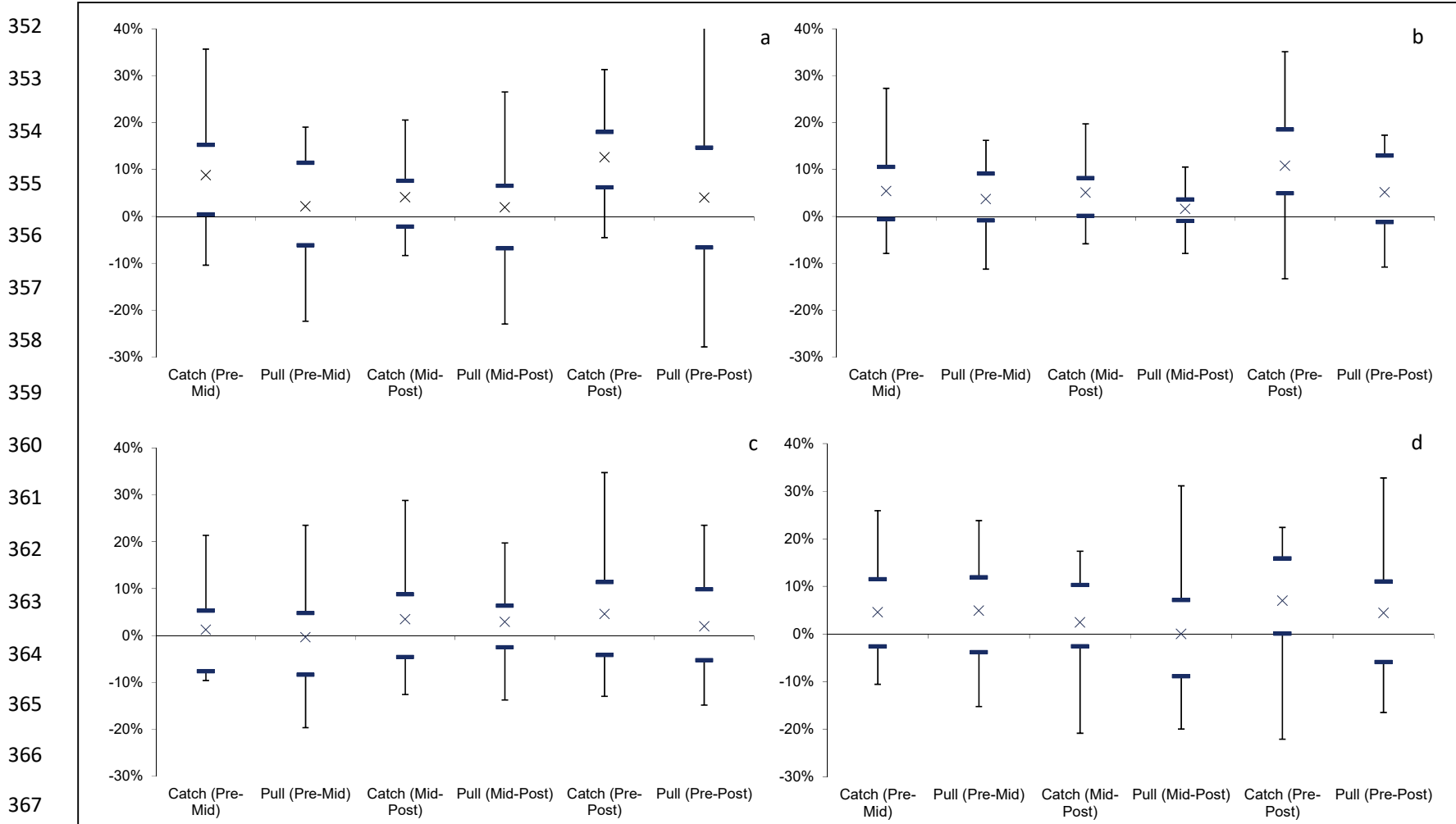


Figure 3: Comparison of percentage change in jump variables, across time points, for the Catch and Pull groups (SJ = squat jump; CMJ = countermovement jump; RSI_{mod} = reactive strength index modified)

368 For CMJ TTT there were trivial to small non-significant differences for both the Catch and Pull
 369 groups across all time points. There were trivial to small and non-significant differences (p
 370 >0.05) in percentage change TTT pre- to mid-intervention ($1.2 \pm 8.8\%$, $-0.4 \pm 12.2\%$, $d = 0.15$),
 371 mid- to post-intervention ($3.5 \pm 11.0\%$, $2.9 \pm 10.6\%$, $d = 0.06$), and pre-post ($4.6 \pm 13.5\%$, 2.0
 372 $\pm 12.0\%$, $d = 0.20$), between the Catch and Pull groups, respectively (Table 5, Figure 3c).
 373 There were only trivial to small changes in RSI_{mod} for both groups across all time points
 374 (Table 5), with trivial to small and non-significant differences ($p > 0.05$) in percentage change
 375 in RSI_{mod} across phases (pre-mid: $4.6 \pm 10.0\%$, $4.9 \pm 10.1\%$, $d = 0.03$, mid-post: $2.4 \pm 10.4\%$,
 376 $0.0 \pm 13.7\%$, $d = 0.20$, pre-post: $7.0 \pm 13.4\%$, $4.4 \pm 14.1\%$, $d = 0.19$), between the Catch and
 377 Pull groups, respectively (Figure 3d).

378

379 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
	d	0.44			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
	d	0.24			0.17		
		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
	d	0.07			0.08		
		0.29			0.11		
RSI _{mod}	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
	d	0.20			0.20		
		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, RSI_{mod}: reactive strength index modified, SD: standard deviation, %CV: percentage coefficient of variation, d : Cohen's d effect size

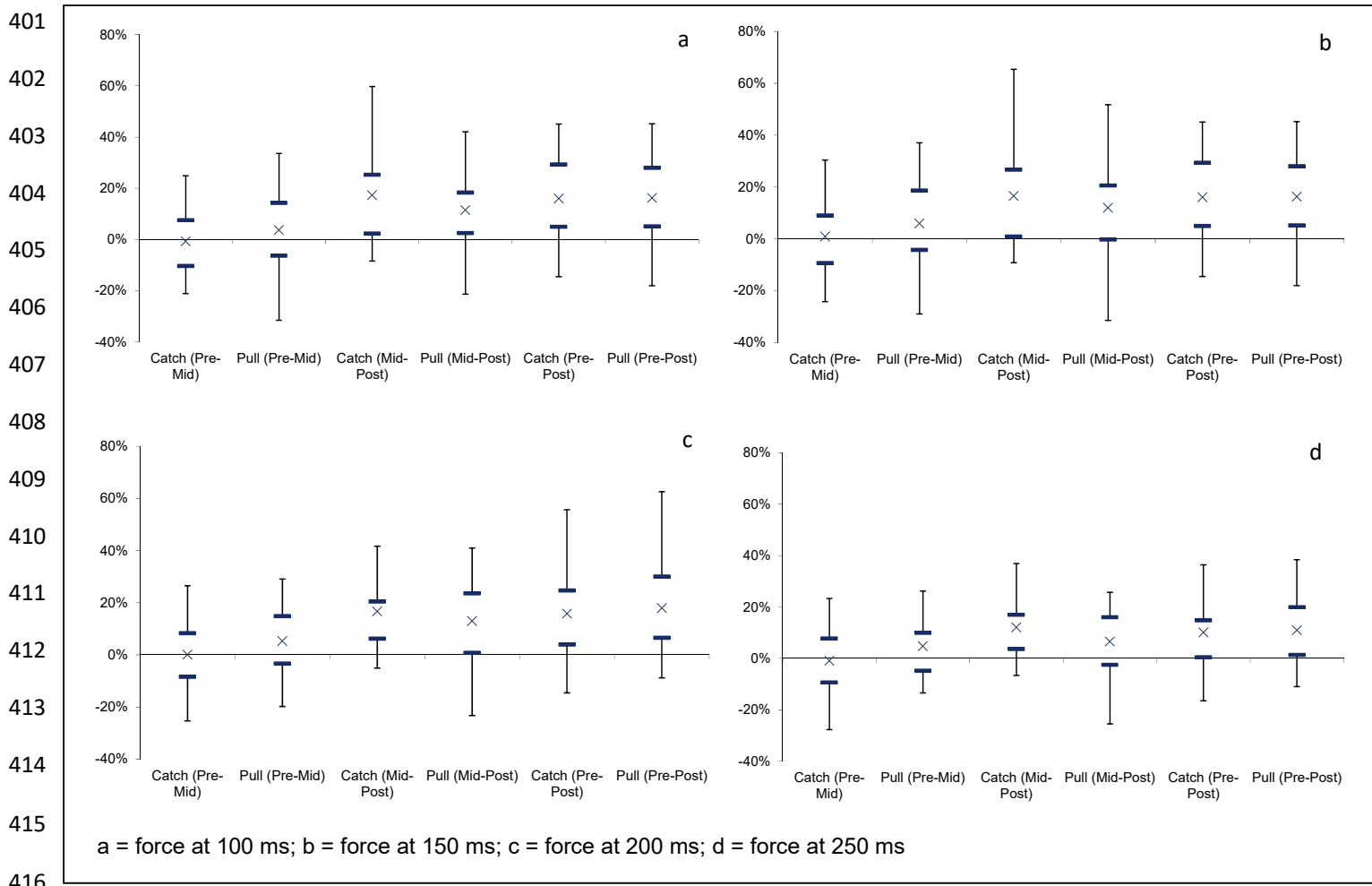
380

381 ISOMETRIC MID-THIGH PULL

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

385 (Catch: $17.3 \pm 22.0\%$, $p = 0.03$ Pull: $11.5 \pm 21.4\%$, $p = 0.04$) increases mid- to post-intervention
386 and pre- to post-intervention (Catch: $14.9 \pm 17.2\%$, $p = 0.011$ Pull: $15.5 \pm 16.0\%$, $p = 0.03$)
387 (Table 6). Trivial to small and non-significant differences ($d = 0.08-0.23$, $p > 0.05$) in percentage
388 change F100 across phases (pre-mid: $-0.7 \pm 13.5\%$, $3.7 \pm 15.9\%$, mid-post: $17.3 \pm 22.0\%$,
389 $11.5 \pm 21.4\%$, pre-post: $14.9 \pm 17.2\%$, $13.5 \pm 16.0\%$), were evident between the Catch and
390 Pull groups, respectively (Figure 4a).

391 Both groups demonstrated significant ($p = 0.005$; power = 0.855) increases in F150, with both
392 groups showing trivial to small non-significant ($p > 0.05$) changes pre- to mid-intervention, with
393 the Catch group demonstrating small significant ($16.5 \pm 20.4\%$, $p = 0.022$) increases mid- to
394 post-intervention and the Pull group demonstrating small but non-significant ($12.0 \pm 22.9\%$, p
395 > 0.05) increases mid- to post-intervention. Both groups demonstrated moderate and
396 significant increases (Catch: $16.0 \pm 17.6\%$, $p = 0.003$ Pull: $16.2 \pm 18.4\%$, $p = 0.01$) in F150
397 pre- to post-intervention (Table 6). Trivial to small and non-significant differences ($d = 0.01-$
398 0.31 , $p > 0.05$) in percentage change F150 across phases (pre-mid: $0.9 \pm 14.9\%$, $5.9 \pm 17.5\%$,
399 mid-post: $16.5 \pm 17.6\%$, $12.0 \pm 22.9\%$, pre-post: $16.0 \pm 17.6\%$, $16.2 \pm 18.4\%$), were evident
400 between the Catch and Pull groups, respectively (Figure 4b).



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

419 Both groups demonstrated significant ($p = 0.007$; power = 0.842) increases in F200. Both
420 groups showed trivial to small non-significant ($p > 0.05$) changes pre- to mid-intervention, with
421 small non-significant (Catch: $16.6 \pm 17.9\%$, Pull: $12.9 \pm 16.8\%$, $p > 0.05$) increases mid- to
422 post-intervention and small, significant increases pre- to post-intervention (Catch: $15.8 \pm$
423 17.6% , $p = 0.017$ Pull: $17.9 \pm 18.3\%$, $p = 0.02$) (Table 6). The Pull group demonstrated small
424 yet significantly greater ($d = 0.38$, $p = 0.002$) increases in F200 pre- to mid-intervention ($5.3 \pm$
425 14.0%) compared to the Catch group ($0.1 \pm 13.2\%$). There were, however, only trivial to small
426 and non-significant differences ($d = 0.12-0.21$, $p > 0.05$) in percentage change F200 mid- to
427 post-intervention ($16.6 \pm 17.9\%$, $12.9 \pm 16.8\%$) or pre- to post-intervention ($15.8 \pm 17.6\%$, 17.9
428 $\pm 18.3\%$), between the Catch and Pull groups, respectively (Figure 4c).

429

430 Both groups demonstrated significant ($p = 0.007$; power = 0.834) increases in F250, with the
431 Catch group showing a trivial non-significant ($p > 0.05$) decrease pre- to mid-intervention, while
432 the Pull group showed a small but non-significant increase ($p > 0.05$). The Catch group
433 demonstrated a small significant ($12.0 \pm 16.6\%$, $p = 0.045$) increase mid- to post-intervention
434 and small significant increase pre- to post-intervention ($10.0 \pm 16.1\%$, $p = 0.025$), while the
435 Pull group demonstrated a small significant ($6.5 \pm 13.4\%$, $p = 0.045$) increase mid- to post-
436 intervention and small significant increase pre- to post-intervention ($10.9 \pm 14.4\%$, $p = 0.025$)
437 (Table 6). Trivial to small and non-significant differences ($d = 0.06-0.47$, $p > 0.05$) in percentage
438 change F250 were evident, across phases (pre-mid: $-1.0 \pm 12.5\%$, $4.7 \pm 11.7\%$, mid-post: 12.0
439 $\pm 16.6\%$, $6.5 \pm 13.4\%$, pre-post: $10.0 \pm 16.1\%$, $10.9 \pm 14.4\%$), between the Catch and Pull
440 groups, respectively (Figure 4d).

441 Both groups demonstrated significant ($p = 0.001$; power = 0.869) and progressive increases
442 in relative PF, with the Catch group showing a trivial non-significant ($p > 0.05$) increase pre- to
443 mid-intervention, while the Pull group showed a small but significant increase ($p = 0.017$). In
444 contrast the Catch group demonstrated a small significant ($8.4 \pm 10.8\%$, $p = 0.028$) increase
445 mid- to post-intervention while the Pull group demonstrated a trivial non-significant ($p > 0.05$)
446 increase in relative PF. Both groups demonstrated small significant increases (Catch: $13.7 \pm$
447 18.7% , $p = 0.021$; Pull: $9.7 \pm 16.3\%$, $p = 0.045$) in relative PF pre- to post-intervention (Table
448 6). The Catch group demonstrated a moderately and significantly greater ($d = 0.84$, $p = 0.014$)
449 increase in PF mid- to post-intervention ($8.4 \pm 10.8\%$) compared to the Pull group ($0.2 \pm 8.5\%$).
450 There were, however, only small and non-significant differences ($d = 0.23-0.45$, $p > 0.05$) in
451 percentage change PF pre- to mid-intervention ($4.6 \pm 9.6\%$, $9.8 \pm 13.1\%$) or pre- to post-
452 intervention ($13.7 \pm 18.7\%$, $9.7 \pm 16.3\%$), between the Catch and Pull groups, respectively
453 (Figure 5a).

454

455

456

457

458

459

460 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
	d	0.01			0.14		
	d	0.46*			0.40*		
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
	d	0.06			0.21		
	d	0.59*			0.33		
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
	d	0.03			0.23		
	d	0.52*			0.29		
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
	d	0.00			0.21		
	d	0.47*			0.23		
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
	d	0.18			0.53*		
	d	0.42*			0.01		
		0.56*			0.48*		

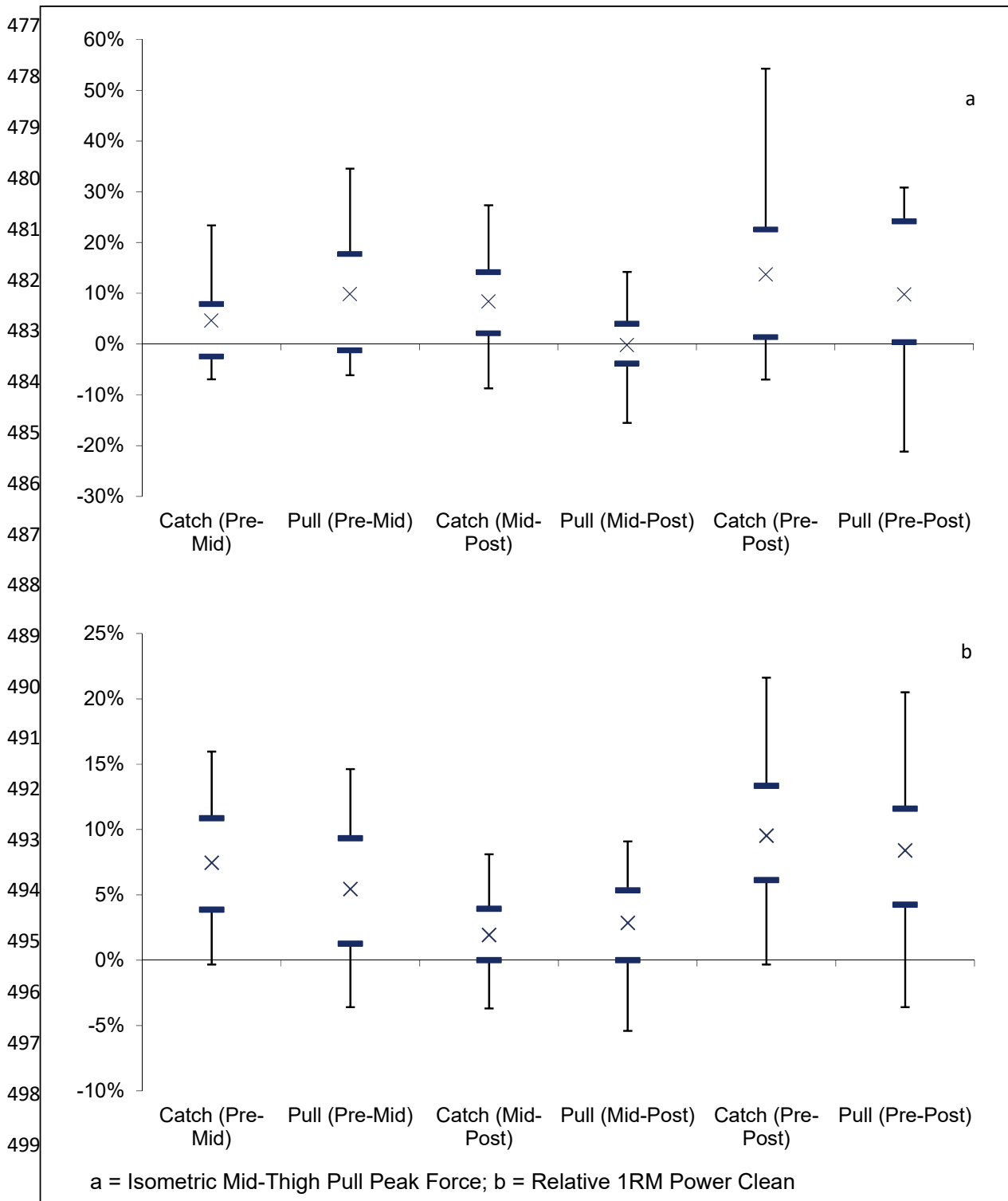
*= significant ($p < 0.05$) increase

461

462 POWER CLEAN

463 For the relative PC, sphericity was assumed via Mauchley's test, with both groups
 464 demonstrating significant ($p < 0.001$; power = 1.00) increases in relative PC 1RM. The Catch
 465 group showed small significant ($d = 0.44$, $p = 0.01$) increases pre- ($0.93 \pm 0.15 \text{ kg.kg}^{-1}$) to mid-
 466 intervention ($0.99 \pm 0.12 \text{ kg.kg}^{-1}$), with trivial non-significant ($d = 0.15$, $p = 0.14$) increases mid-
 467 to post-intervention ($1.01 \pm 0.14 \text{ kg.kg}^{-1}$), resulting in a small significant ($d = 0.55$, $p < 0.001$)
 468 increase pre- to post-intervention (Figure 5b). The Pull group showed small significant ($d =$
 469 0.23 , $p = 0.001$) increases pre- ($0.91 \pm 0.18 \text{ kg.kg}^{-1}$) to mid-intervention ($0.95 \pm 0.17 \text{ kg.kg}^{-1}$),

470 with trivial, yet significant ($d = 0.17$, $p = 0.015$) increases mid- to post-intervention (0.98 ± 0.18
 471 $\text{kg}\cdot\text{kg}^{-1}$), resulting in a small significant ($d = 0.39$, $p < 0.001$) increase pre- to post-intervention.
 472 There were small non-significant differences ($p > 0.05$) in percentage change in relative PC
 473 performance pre- to mid-intervention ($7.4 \pm 5.0\%$, $5.4 \pm 5.4\%$, $d = 0.38$) mid- to post-
 474 intervention ($1.9 \pm 0.8\%$, $2.9 \pm 4.1\%$, $d = 0.34$) and only trivial differences pre- to post
 475 intervention ($9.5 \pm 6.2\%$, $8.4 \pm 6.1\%$, $d = 0.18$) between the Catch and Pull groups, respectively
 476 (Figure 5b).



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

503

504 There were no significant ($p > 0.05$) changes in body mass for either the Catch (Pre $71.14 \pm$
505 11.79 kg; Mid 71.03 ± 11.48 kg; Post 70.95 ± 11.07 kg) or the Pull group (Pre 66.43 ± 10.13
506 kg; Mid 66.64 ± 9.97 kg; Post 66.68 ± 10.11 kg) across the duration of the intervention.

507

508 Discussion

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

517

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

538 Both groups demonstrated trivial to small and non-significant increases in time-specific force
539 values during the initial four weeks (pre- to mid- intervention), with small to moderate and
540 significant increases in the final four weeks (mid- to post-intervention). This resulted in small
541 to moderate increases in F100 (14.9%; 15.5%), F150 (16.0%; 16.2%), F200 (15.8%; 17.9%)
542 and F250 (15.8%; 17.9%) for the Catch and Pull groups respectively. The greater increases

543 in time-specific force production, during the second four weeks of training, may be due the
544 higher intensities used, resulting in the subjects having to ensure a maximal intent and rapid
545 force production to adequately accelerate the barbell. The Pull group consistently
546 demonstrated a greater percentage change in all time-specific forces although these
547 differences were small and non-significant (Figure 4). These observations are similar to those
548 previously reported by Oranchuk et al. (37) who also reported no meaningful differences in
549 relative PF and time-specific force variables, after 10-weeks of hang high pull versus
550 hexagonal barbell jump squat training.

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

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

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

588 emphasize either a force or velocity overload stimulus, as described by Suchomel et al., (43),
589 compared to training with weightlifting catching derivatives.

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

595

596 **Practical Application**

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

608

609

610

611 *Acknowledgements: The authors would like to acknowledge Matthew Cuthbert, Rachel*
612 *Higgins and Daniel Traynor for their assistance during the coaching sessions. We would also*
613 *like to thank the participants for their time and efforts, and the NSCA for supporting this*
614 *investigation as part of the International Collaboration Grant.*

615

616 *Funding: This study was funded by the NSCA foundation, as part of the International*
617 *Collaboration Grant scheme (awarded 2016).*

618

619 *The authors report no conflict of interest and the finding of the study do not represent the views*
620 *of the NSCA.*

621

622

623

624

625 **References**

- 626 1. Baechle TR, Earle RW, and Wathen D. Resistance Training, in: *Essentials of Strength Training*
627 *and Conditioning*. TR Baechle, Earle, R. W, ed. Champaign, Illinois: Human Kinetics, 2008, pp
628 381-412.
- 629 2. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey M, Lamont H, Hornsby G, Haff G, and
630 Stone M. Relationships of isometric mid-thigh pull variables to weightlifting performance. *J*
631 *Sports Med Phys Fitness* 53: 573-581, 2013.
- 632 3. Beckham GK, Sato K, Mizuguchi S, Haff GG, and Stone MH. Effect of Body Position on Force
633 Production During the Isometric Mid-Thigh Pull. *J Strength Cond Res*. Publish Ahead of Print,
634 2017.
- 635 4. Canavan PK, Garrett GE, and Armstrong LE. Kinematic and Kinetic Relationships Between an
636 Olympic-Style Lift and the Vertical Jump. *J Strength Cond Res*. 10: 127-130, 1996.
- 637 5. Comfort P, Allen M, and Graham-Smith P. Comparisons of peak ground reaction force and
638 rate of force development during variations of the power clean. *J Strength Cond Res* 25:
639 1235-1239, 2011.
- 640 6. Comfort P, Graham-Smith P, and Allen M. Kinetic comparisons during variations of the
641 Power Clean. *J Strength Cond Res* 25: 3269-3273, 2011.
- 642 7. Comfort P, Jones PA, McMahan JJ, and Newton R. Effect of knee and trunk angle on kinetic
643 variables during the isometric midhigh pull: test-retest reliability. *Int J Sports Physiol*
644 *Perform* 10: 58-63, 2015.
- 645 8. Comfort P, Jones PA, and Udall R. The effect of load and sex on kinematic and kinetic
646 variables during the mid-thigh clean pull. *Sports Biomech* 14: 139-156, 2015.
- 647 9. Comfort P and McMahan JJ. Reliability of Maximal Back Squat and Power Clean
648 Performances in Inexperienced Athletes. *J Strength Cond Res*. 29: 3089-3096, 2015.
- 649 10. Comfort P, Udall R, and Jones P. The affect of loading on kinematic and kinetic variables
650 during the mid-thigh clean pull. *J Strength Cond Res* 26: 1208-1214, 2012.
- 651 11. Comfort P, Williams R, Suchomel TJ, and Lake JP. A comparison of catch phase force-time
652 characteristics during clean derivatives from the knee. *J Strength Cond Res*. 21 (7): 2017.
- 653 12. Cormack SJ, Newton RU, McGuigan MR, and Doyle TL. Reliability of measures obtained
654 during single and repeated countermovement jumps. *Int J Sports Physiol Perform* 3: 131-144,
655 2008.
- 656 13. Dos'Santos T, Jones PA, Comfort P, and Thomas C. Effect of Different Onset Thresholds on
657 Isometric Mid-Thigh Pull Force-Time Variables. *J Strength Cond Res* Publish Ahead of Print,
658 2017.
- 659 14. Dos'Santos T, Thomas C, Comfort P, McMahan JJ, Jones PA, Oakley NP, and Young AL.
660 Between-Session Reliability Of Isometric Mid-Thigh Pull Kinetics And Maximal Power Clean
661 Performance In Male Youth Soccer Players. *J Strength Cond Res* Published ahead of print,
662 2017.
- 663 15. Dos'Santos T, Thomas C, Jones PA, McMahan JJ, and Comfort P. The Effect Of Hip Joint Angle
664 On Isometric Mid-Thigh Pull Kinetics. *J Strength Cond Res*. Publish Ahead of Print, 2017.
- 665 16. Enoka RM. The pull in olympic weightlifting. *Med Sci Sports* 11: 131-137, 1979.
- 666 17. Faigenbaum AD, McFarland JE, Herman RE, Naclerio F, Ratamess NA, Kang J, and Myer GD.
667 Reliability of the one-repetition-maximum power clean test in adolescent athletes. *J*
668 *Strength Cond Res* 26: 432-437, 2012.
- 669 18. Garhammer J and Gregor R. Propulsion Forces as a Function of Intensity for Weightlifting
670 and Vertical Jumping. *J Strength Cond Res*. 6: 129-134, 1992.
- 671 19. Haff GG, Carlock JM, Hartman MJ, Kilgore JL, Kawamori N, Jackson JR, Morris RT, Sands WA,
672 and Stone MH. Force-time curve characteristics of dynamic and isometric muscle actions of
673 elite women olympic weightlifters. *J Strength Cond Res* 19: 741-748, 2005.

- 674 20. Haff GG, Ruben RP, Lider J, Twine C, and Cormie P. A Comparison of Methods for
675 Determining the Rate of Force Development During Isometric Mid-Thigh Clean Pulls. *J*
676 *Strength Cond Res* 29: 386-395, 2015.
- 677 21. Haff GG, Stone M, O'Bryant HS, Harman E, Dinan C, Johnson R, and Han K-H. Force-Time
678 Dependent Characteristics of Dynamic and Isometric Muscle Actions. *J Strength Cond Res* 11:
679 269-272, 1997.
- 680 22. Haff GG, Whitley A, McCoy LB, O'Bryant HS, Kilgore JL, Haff EE, Pierce K, and Stone MH.
681 Effects of Different Set Configurations on Barbell Velocity and Displacement During a Clean
682 Pull. *J Strength Cond Res* 17: 95-103, 2003.
- 683 23. Halperin I, Williams KJ, Martin DT, and Chapman DW. The Effects of Attentional Focusing
684 Instructions on Force Production During the Isometric Midthigh Pull. *J Strength Cond Res* 30:
685 919-923, 2016.
- 686 24. Halperin I, Williams KJ, Martin DT, and Chapman DW. The Effects of Attentional Focusing
687 Instructions on Force Production During the Isometric Midthigh Pull. *J Strength Cond Res*. 30:
688 919-923, 2016.
- 689 25. Harbili E and Alptekin A. Comparative kinematic analysis of the snatch lifts in elite male
690 adolescent weightlifters. *J Sports Sci Med* 13: 417-422, 2014.
- 691 26. Helland C, Hole E, Iversen E, Olsson MC, Seynnes O, Solberg PA, and Paulsen G. Training
692 Strategies to Improve Muscle Power: Is Olympic-style Weightlifting Relevant? *Med Sci Sports*
693 *Exerc* 49: 736-745, 2017.
- 694 27. <http://sportsci.org/resource/stats/index.html>. Accessed 08/05/15/2015.
- 695 28. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in
696 sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.
- 697 29. Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR, and Nosaka K. Does
698 Performance of Hang Power Clean Differentiate Performance of Jumping, Sprinting, and
699 Changing of Direction? *J Strength Cond Res* 22: 412-418 2008.
- 700 30. Kavanaugh AA, Mizuguchi S, Sands WA, Ramsey MW, and Stone MH. Long-Term Changes In
701 Jump Performance And Maximum Strength In A Cohort Of Ncaa Division I Women's
702 Volleyball Athletes. *J Strength Cond Res* Publish Ahead of Print, 2017.
- 703 31. Kawamori N, Rossi SJ, Justice BD, Haff EE, Pistilli EE, O'Bryant HS, Stone MH, and Haff GG.
704 Peak Force and Rate of Force Development During Isometric and Dynamic Mid-Thigh Clean
705 Pulls Performed At Various Intensities. *J Strength Cond Res* 20: 483-491, 2006.
- 706 32. Kipp K, Malloy PJ, Smith J, Giordanelli MD, Kiely MT, Geiser CF, and Suchomel TJ. Mechanical
707 Demands of the Hang Power Clean and Jump Shrug: A Joint-level Perspective. *J Strength*
708 *Cond Res* Publish Ahead of Print, 2017.
- 709 33. McGuigan M and Winchester JB. The relationship between isometric and dynamic strength
710 in collegiate football players. *J Sports Sci Med* 7: 101-105, 2008.
- 711 34. McMahon JJ, Jones PA, Suchomel TJ, Lake J, and Comfort P. Influence of Reactive Strength
712 Index Modified on Force- and Power-Time Curves. *Int J Sports Physiol Perform* E-pub ahead
713 of print: 1-24, 2017.
- 714 35. Moir GL. Three Different Methods of Calculating Vertical Jump Height from Force Platform
715 Data in Men and Women. *Measurement in Physical Education and Exercise Science* 12: 207-
716 218, 2014.
- 717 36. Moolyk AN, Carey JP, and Chiu LZF. Characteristics of Lower Extremity Work During the
718 Impact Phase of Jumping and Weightlifting. *J Strength Cond Res* 27: 3225-3232, 2013.
- 719 37. Oranchuk DJ, Robinson TL, Switaj ZJ, and Drinkwater EJ. Comparison of the Hang High-Pull
720 and Loaded Jump Squat for the Development of Vertical Jump and Isometric Force-Time
721 Characteristics. *J Strength Cond Res*, 2017.
- 722 38. Owen NJ, Watkins J, Kilduff LP, Bevan HR, and Bennett MA. Development of a criterion
723 method to determine peak mechanical power output in a countermovement jump. *J*
724 *Strength Cond Res* 28: 1552-1558, 2014.

- 725 39. Souza AL, Shimada SD, and Koontz A. Ground reaction forces during the power clean. *J*
726 *Strength Cond Res* 16: 423-427, 2002.
- 727 40. Stone MH, Sanborn KIM, O'Bryant HS, Hartman M, Stone ME, Proulx C, Ward B, and Hruby
728 JOE. Maximum Strength-Power-Performance Relationships in Collegiate Throwers. *J Strength*
729 *Cond Res* 17: 739-745, 2003.
- 730 41. Suchomel T, Comfort P, and Stone M. Weightlifting Pulling Derivatives: Rationale for
731 Implementation and Application. *Sports Medicine* 45: 823-839, 2015.
- 732 42. Suchomel TJ, Bailey CA, Sole CJ, Grazer JL, and Beckham GK. Using reactive strength index-
733 modified as an explosive performance measurement tool in Division I athletes. *J Strength*
734 *Cond Res* 29: 899-904, 2015.
- 735 43. Suchomel TJ, Comfort P, and Lake JP. Enhancing the Force-Velocity Profile of Athletes Using
736 Weightlifting Derivatives. *Strength & Conditioning Journal* 39: 10-20, 2017.
- 737 44. Suchomel TJ, Lake JP, and Comfort P. Load absorption force-time characteristics following
738 the second pull of weightlifting derivatives. *J Strength Cond Res* 31: 1644-1652, 2017.
- 739 45. Suchomel TJ and Sole CJ. Force-Time Curve Comparison Between Weightlifting Derivatives.
740 *International Journal of Sports Physiology and Performance* Published ahead of print, 2017.
- 741 46. Suchomel TJ and Sole CJ. Power-Time Curve Comparison between Weightlifting Derivatives.
742 *J Sports Sci Med* 16: 407-413, 2017.
- 743 47. Suchomel TJ, Wright GA, Kernozek TW, and Kline DE. Kinetic Comparison of the Power
744 Development Between Power Clean Variations. *J Strength Cond Res* 28: 350-360, 2014.

745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770

771 **Figure and Table Legends:**

- 772
773 Figure 1: Summary of testing schedule
- 774 Figure 2: Testing sequence (SJ: squat jump, CMJ: countermovement jump, IMTP: Isometric
775 Mid-Thigh Pull)

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

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

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

782

783

784 Table 1: Training sessions, weeks 1-4

785 Table 2: Training sessions, weeks 6-9

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

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

790 Table 5: Changes in jump performance

791 Table 6: Changes in isometric mid-thigh pull performance