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Abstract

This study examined the effects of resistance training on muscular strength and jump performance in young male swimmers. It was hypothesized that adaptations would be of a lower magnitude in less mature (Pre-peak height velocity [PHV]) than in more mature (Post-PHV) subjects. Fourteen Pre- (-1.8 ± 1.0 years) and 8 Post-PHV (1.6 ± 0.5 years) swimmers undertook a 30 minute, twice-weekly resistance training program for 8 weeks. They were compared with matched control groups (Pre-PHV: -2.0 ± 1.1 , $n=15$; Post-PHV: 1.2 ± 1.0 , $n=7$). The effects on lower body isometric strength (LBS), measured with mid-thigh pull, and vertical jump (VJ) height in the Post-PHV group were large (effect size: 1.3 [0.4 to 2.2]) and small (0.4 [-0.4 to 1.2]) respectively. Effects on LBS and VJ height in the Pre-PHV group were moderate (0.8 [0.1 to 1.4]) and trivial (0.2 [-0.5 to 0.8]) respectively. Estimates in the Post-PHV control group (LBS: 0.7 [-0.2 to 1.6]; VJ: 0.2 [-0.7 to 1.0]) and the Pre-PHV control group (LBS: 0.1 [-0.5 to 0.7]; VJ: -0.3 [-0.9 to 0.3]) may indicate the extent to which maturation could contribute to the performance changes seen in the respective training groups. LBS and VJ are trainable, but to different magnitudes, in Pre- and Post-PHV swimmers. Following appropriate foundational training to establish technical competency, twice-weekly resistance training sessions of 30 minutes duration, comprising 3 sets of 4 exercises can be effective in Pre-PHV and Post-PHV youth.

Keywords: Trainability, strength, youth, athletes, swimming.

47 **INTRODUCTION**

48 Maximal strength is the maximum force skeletal muscles can exert in an action (29).
49 Strength is well correlated with sprint ($r=0.672$) and jump ($r=0.760$) performance (7) and can
50 help to reduce injury rates (16). Physical strength is also required to carry out fundamental
51 movement skills and to underpin long term commitment to physical activity (32).
52 Recommendations suggest no minimum age for participation in resistance training but youth
53 should be technically proficient before embarking on a program (9). On this, neuromuscular
54 coordination can vary in athletes of the same chronological age (43) whilst adaptations can
55 differ between youth of disparate maturity status (40, 53) due to issues relating to movement
56 efficiency and hormonal profile (43). These are important considerations in programing as
57 guidelines for exercise in youth have thus far been generic, particularly for less mature or
58 experienced children who may need to overcome issues relating to strength and motor
59 control to optimise performance.

60 Current literature is undermined by a number of limitations relating to the biological maturity
61 status of youth in addition to the specificity of the training stimulus with respect to stages of
62 maturation. Historically, controlled trials (31, 47, 61) have demonstrated improvements in
63 strength following exposure to resistance training but have measured maturity status in
64 different ways making comparisons to recent studies difficult. Over the last number of years,
65 researchers have started reporting the maturity offset (years before and after peak height
66 velocity [PHV] (41)) of trial subjects (40, 53) and more recently, the first controlled studies,
67 which measure maturity offset in resistance-training athletes (20, 52), have emerged. Both of
68 these studies involved youth soccer players who were subjected to concurrent training
69 modalities including squat, sprint and jump exercises on a twice-weekly basis with the
70 authors examining the effects on equivalent performance parameters. However, only one
71 resisted exercise was performed in the program each day.

72 Maturity offset (41) is an objective and practical method to assess maturation and is used in
73 professional sports (59, 63). Though not without limitations (41), the method has been used
74 to form grouping variables in a variety of recently published interventions and reviews
75 examining training types in youth (33, 40, 42, 43, 48, 53, 54). Additionally, many researchers
76 have failed to measure programs' effects on a measure of maximum muscular strength,
77 preferring instead to assess responses in jumping and sprinting performance (21, 33, 48,
78 55). This is an important consideration in light of the specificity of adaptive responses to
79 different training modalities (60). Also, recent controlled trials in youth demonstrated
80 moderate to large gains in strength over a 6 week period but because resistance training
81 was combined with sprint and plyometric training, it is difficult to specify the effect of
82 resistance training in youth of a certain maturity status (20, 52). Furthermore, controlled
83 studies have generally not compared adaptations in groups of different maturity status as
84 delineated with the maturity offset. Two recent studies (40, 53) did adopt this approach but
85 did not include control groups making it difficult to partition the effects of training and
86 maturation. On this, Radnor et al. (48) and Lloyd et al. (33) did include control groups and a
87 measure of maturity status but preferred to assess resistance training's effect on jumping
88 and sprinting performance.

89 To date, no researchers have sought to address all of the above limitations within the same
90 study and this undermines the quality of inferences that can be made from the literature. The
91 purpose of this study was to examine the effects of resistance training, deliberately without
92 sprints and plyometrics, on performance in Pre-PHV and Post-PHV male subjects,
93 incorporating control groups and a measure of muscular strength. Recent evidence on
94 strength training in youth has been somewhat equivocal. A meta-analysis by Behringer et al.
95 (3) showed that younger trainees had greater increases in motor performance in response to
96 resistance training. However, recent non-controlled trials have shown that resistance training
97 has had greater effects on muscular strength in more mature youth athletes (40, 53). On that

98 basis, it was hypothesized that adaptations in strength and power would be of a larger
99 magnitude in more mature (Post-PHV) than in less mature (Pre-PHV) youth swimmers.

100 **METHODS**

101 **Experimental approach to the problem**

102 This study was carried out to assess the effects of resistance training on performance in Pre-
103 PHV and Post-PHV male swimmers with a view to testing the hypothesis that the more
104 mature group (Post-PHV) would demonstrate greater adaptations. Addressing the limitations
105 of previous research, it was a deliberate design feature to include training groups of different
106 maturation status to facilitate testing of the hypothesis. Accordingly, the groups were divided
107 on the basis that synergistic adaptations to resistance exercise may occur due to the
108 combined effects of training and maturation in more mature (Post-PHV) youth (14).
109 Additionally, control groups were incorporated to account for non-training related changes in
110 performance while a measure of biological maturity and, also, muscular strength was used to
111 determine if changes in strength were dependent on maturity status. The measure of
112 biological maturity status proposed by Mirwald et al. (41) was utilised to differentiate the
113 study groups as it is a commonly used method in youth sport. Before and after the 8 week
114 training intervention period, tests were carried out to assess upper body strength (UBS [hand
115 grip peak force]), vertical jump (VJ) and lower body strength (LBS [isometric mid-thigh pull
116 peak force]) as these were considered to be measures that would be likely to show an effect
117 due to the training stimulus (14).

118 **Subjects**

119 The study was approved by the university's ethics committee and written informed consent
120 was obtained from parents and subjects. It was undertaken in accordance with the
121 Declaration of Helsinki. Youth swimmers were recruited through local swimming clubs. The
122 experimental group (n=22) was recruited from a single club to provide access to training
123 facilities. To avoid contamination, the control group (n=22) was drawn from multiple clubs

124 (n=4). Because of this, randomization was not feasible. The characteristics of the subjects
125 are in Table 1. Subjects ranged from -3.9 to +3.1 years either side of PHV and were divided
126 into Pre-PHV (Experimental: n = 14; Control = 15) and Post-PHV (Experimental: n = 8;
127 Control = 7) groups for analysis, as recommended by Mirwald et al. (41) (Pre-PHV = <0.0
128 years from PHV; Post-PHV = ≥ 0.0 years from PHV).

129 **[Table 1 near here]**

130 **Procedures**

131 Subjects performed fitness tests in the week before and the week after the training
132 intervention. Testing was carried out by a team of sports scientists from the university's
133 Sports and Exercise department. To estimate maturity status, anthropometric measurements
134 were taken and entered into an equation to predict maturity offset (41). Following this, the
135 tests of UBS, VJ and LBS were undertaken. Sitting and standing height were measured with
136 a stadiometer (Seca, Leicester, United Kingdom) and body mass with a portable scales
137 (HoMedics Group Limited, Kent, United Kingdom).

138 UBS was measured with a Takei T.K.K.5001 GRIP A handgrip dynamometer (Takei
139 Scientific Instruments Co. Ltd, Tokyo, Japan). Excellent test-retest reliability ($r=0.97$) was
140 observed for this measure which was in line with previous work (46). The dynamometer was
141 adjusted to the hand size of each subject (5). Hand span was measured with tape and was
142 taken as the distance between the little finger and the thumb when the hand was widely
143 opened, with optimal grip spans corresponding to previous measurements (11). The
144 dominant hand was used with the subject in a standing position, the elbow extended and the
145 wrist held neutral. The used arm was allowed to deviate from 180 degrees of flexion to near
146 0 degrees. The subjects were given a verbal countdown to performance of "3, 2, 1, squeeze"
147 and exerted maximal force for a period of 5 seconds. Following two efforts with at least 2
148 minutes of rest between each, the highest observed score was recorded for analysis (5). The

149 digital version of this equipment has been shown to be acceptably reliable across trials
150 (inter-trial difference: 0.3 ± 2.5 kg) (46).

151 To assess vertical jump, a Newtest Powertimer jump mat (Newtest OY, Oulu, Finland) was
152 used. Excellent test-retest reliability ($r=0.92$) was observed for this measure which was in
153 line with previous work (57). Jump tests in youth have shown this apparatus to be highly
154 reliable (39). Subjects executed a downward movement to a self-selected depth before
155 performing an explosive extension of the lower-body limbs to jump as high as possible (8).
156 To facilitate maximal performance, participants were permitted to utilise an arm-swing
157 movement as desired during the jump (22). There was at least one minute's rest between
158 efforts and the highest of three trials was used in the analysis.

159 LBS was measured with a portable cable pull apparatus (Takei A5002, Fitness Monitors,
160 Wrexham, United Kingdom) which has a high intraclass correlation coefficient ($r=0.98$) (28).
161 Excellent test-retest reliability ($r=0.89$) was observed for this measure which was in line with
162 previous work (28). The apparatus can be viewed in Figure 1. Subjects were instructed to
163 assume an upright body position with the knees bent to approximately 160 degrees (28).
164 The lumbar spine was arched and the trunk was inclined forward such that the pulling handle
165 rested halfway up the thigh between the midpoint of the patella and the iliac crest (6).
166 Following the assumption of a safe body-position (2), subjects were given a verbal
167 countdown to performance of "3, 2, 1, pull". With verbal encouragement (2), each subject
168 exerted maximal force for a period of 5 seconds (6). Between each effort, subjects were
169 instructed to rest for 3 minutes (6) and the best of two trials was used for analysis. The unit
170 of measurement for the MTP was kilogram-force (kgf) with one unit being the equivalent of
171 9.806N (58).

172 The three performance tests were undertaken in the order described with the difference
173 between the coefficient of variation for baseline and follow-up measures ranging from 2.4%
174 to 3.9%.

175 **[Figure 1 near here]**

176 **Training**

177 The resistance training programme (Table 2) conformed to the guidelines for youth of the
178 National Strength and Conditioning Association (13) and was delivered every day by the
179 lead researcher who is an accredited strength and conditioning coach (UKSCA), and other
180 qualified personnel. Prior to the beginning of each session a general warm-up (5-10 mins),
181 consisting of skipping, crawling and various other upper and lower body movements, was
182 performed. Training sessions were scheduled on four days each week and subjects were
183 instructed to attend on two non-consecutive days. Prior to undertaking the 8 week
184 intervention study, subjects engaged in an introductory week during which they were
185 familiarised with the session format and proper exercise technique.

186 **[Table 2 near here]**

187 During the sessions, subjects were instructed to use manageable loads such that safe and
188 technically proficient performance was not compromised. Each subject was encouraged to
189 lift the maximum weight possible for the prescribed number of repetitions. When subjects
190 were capable of performing more than the prescribed number of repetitions, they were asked
191 to increase the load by between 5% and 10%. In such cases, they were permitted to perform
192 the work set to near muscular failure before adjusting the load to the higher level.
193 Conversely, if they were unable to complete the work set, they were instructed to decrease
194 the load by 5% to 10%. For the push up exercise, subjects were given a repetition guideline
195 but were encouraged to continue performance until near muscular failure or until one of the
196 coaches had judged that technical breakdown could occur. For the side plank and plank
197 exercises, time guidelines were provided but subjects were allowed to extend performance
198 up to a maximum of 30 seconds (each side), and 1 minute respectively. In the final week of
199 each four week cycle, maximum repetitions or time were encouraged up to the point that
200 proper technique could be maintained on each exercise.

201 As available training time was limited, sessions followed a specific format. The first sets of all
202 four exercises were performed in a continuous manner with low-intensity mobility exercises
203 used as active rest between each. These included side-lying rotations, leg lowering, floor
204 slides and hip-flexor stretching. Using phase 1 as an example, the subjects would perform a
205 single set of goblet squats, using side-lying rotations as a means of active rest before
206 performing a single set of push ups, followed by the leg-lowering mobility exercise and
207 continuing on to the third and fourth exercises accordingly. After this, 2 to 3 minutes of
208 complete rest was taken before moving on to the second set of goblet squats and performing
209 all subsequent exercises in a continuous manner once again. This form of “super-setting” is
210 considered to be effective for carrying out resistance training when available time is a limiting
211 factor (26) and exercises were arranged in such a way that upper and lower body
212 movements were alternated to preserve technical competency in each. After 4 weeks of the
213 intervention, the resistance exercises were progressed to maintain subjects’ engagement
214 and to increase the demands of the program.

215 The average ratio of subjects to coaches in the intervention was approximately 5 to 1. The
216 average attendance rate during the intervention was 89.2%. To complete the study, a
217 subject must have attended 75% of all training sessions to ensure that a sufficient volume of
218 training was undertaken. Subjects tracked progress in a diary which was observed by the
219 lead researcher. Also, to estimate workload, immediately after each training session,
220 subjects reported their perceived exertion (RPE) for the entire session on a 1 to 10 scale.
221 This figure was multiplied by the training session duration in minutes to establish a ‘session-
222 RPE’ score (19).

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227 **Statistical analysis**

228 Magnitude-based inferences were preferred to traditional null hypothesis testing which can
229 be biased by small sample sizes (51) and can be ineffective in gauging practical importance
230 (24). Effect sizes were interpreted using previously outlined ranges (<0.2 = trivial; 0.2-0.6 =
231 small, 0.6-1.2 = moderate, 1.2-2.0 = large, 2.0-4.0 = very large, >4.0 = extremely large) (24).
232 An effect size of 0.2 was considered to be the 'smallest worthwhile change' (56). The
233 estimates were considered unclear when the chance of a beneficial effect was high enough
234 to justify use of the intervention, but the risk of impairment was unacceptable. An odds ratio
235 of benefit to impairment of <66 was representative of such unclear effects (40). This odds
236 ratio corresponds to an effect that is borderline possibly beneficial (25% chance of benefit)
237 and borderline most unlikely detrimental (0.5% risk of harm). This was calculated using an
238 available spreadsheet (23). Otherwise, the effect was considered as clear and was reported
239 as the magnitude of the observed value, with the qualitative probability that the true value
240 was at least of this magnitude (40). The scale for interpreting the probabilities was as
241 follows: possible = 25–75%; likely = 75–95%; very likely = 95–99.5%; most likely >99.5%
242 (24).

243 Uncertainty in the effect sizes was represented by 90% confidence limits. Effects were
244 considered unclear if the confidence interval overlapped thresholds for substantial positive
245 and negative values. Otherwise, the effect was clear and reported as the magnitude of the
246 observed value with a qualitative probability (24, 40). The utilised confidence limits of 90%
247 are important in intervention studies in which one is presented with an inexpensive
248 intervention that is most unlikely to be harmful, but likely to be at least trivially beneficial (23).

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252 **RESULTS**

253 Effect sizes and their descriptors and likelihood estimates of beneficial effects are shown in
254 Tables 3 (baseline to follow up) and 4 (follow up only).

255 **[Table 3 near here]**

256 The within-group baseline to follow-up analysis showed LBS increased across both groups
257 and was of large magnitude in the Post-PHV group and moderate in the Pre-PHV group.
258 Comparison of follow-up tests in both Pre-PHV and Post-PHV groups and their controls were
259 reflective of this finding. The Post-PHV control group improved LBS to a greater extent than
260 the Pre-PHV control group. Predominantly small and trivial changes were seen in UBS
261 across experimental and control groups in both maturity categories. The Post-PHV group
262 showed a small 'likely beneficial' effect for VJ and the Pre-PHV group showed a trivial effect
263 in the within-group analysis. However, the between-group comparisons showed substantially
264 larger post-intervention changes in the Pre-PHV group than in the Post-PHV group. Once
265 again, the Post-PHV control group showed larger changes than the Pre-PHV group.

266 **[Table 4 near here]**

267 The training load data for the training intervention can be viewed in Figure 2 and Table 5.
268 Only small and trivial changes were found between both experimental groups.

269 **[Figure 2 near here]**

270 **[Table 5 near here]**

271 **DISCUSSION**

272 This study compared the effects of a resistance training program in male swimmers of
273 differing biological maturation status. It was hypothesized that more mature (Post-PHV)
274 subjects would adapt at a greater magnitude than less mature (Pre-PHV). The study sought
275 to account for limitations in previous research by including control groups, measures of

276 muscular strength and comparable maturity groups within the same investigation, something
277 which has not previously been achieved. The most important finding was that strength
278 seems more trainable in Post-PHV youth than in Pre-PHV and the effect sizes for LBS in
279 each group confirmed this. Also notable was that despite the pure intervention effect on VJ
280 being smaller in the Pre-PHV group, VJ performance could be more responsive to resistance
281 training in Pre-PHV.

282 Previous interventions in youth athletes (40, 53) have shown that resistance training in the
283 Pre-PHV stage may be less effective for increasing strength than it is in the Post-PHV stage.
284 Meylan et al. (40) found that maximal strength was less trainable in Pre-PHV athletes and
285 more transient following a detraining period when compared to Mid- and Post-PHV athletes.
286 Similarly, Rumpf et al. (53) reported that Pre-PHV athletes failed to improve resisted sprint
287 performance as compared to a Mid-/Post-PHV group which showed significant increases.
288 However, neither of these studies included a control group which makes it difficult to fully
289 evaluate the training methods and impossible to differentiate between changes due to
290 training and biological maturation.

291 Structural development of muscle mass can occur in response to hormonal changes during
292 adolescence (32). Also, an influential factor in the ability to exert force is the cross-sectional
293 area of a muscle (18). Accordingly, as the Pre-PHV group's ability to increase muscular size
294 was likely lower than the Post-PHV group's, the less mature subjects may have been more
295 dependent on neural mechanisms for the enhancement of strength. The lower effect size
296 seen in Pre-PHV could be indicative of fewer available pathways of adaptation in
297 comparison to the Post-PHV group. This is supported by previous research (62) which
298 revealed that tendon cross-sectional area remained unaffected following resistance training
299 in prepubertal children, despite an increase in tendon stiffness of 29%. Moreover, it has
300 been demonstrated that increased strength in prepubertal boys can occur without changes in
301 muscular size with strength adaptations attributed to enhanced excitation-contraction
302 coupling (50).

303 Performance improvements are likely to occur due to the interaction between training and
304 maturation (13, 44). Interestingly, moderate changes in LBS were seen in the Post-PHV
305 control group. This contrasts with the changes in LBS in the Pre-PHV control group, which
306 improved only trivially. The disparate effects observed in the control groups could suggest
307 that maturation-related increases in strength influenced performance in the Post-PHV group
308 though over the short study period this could also be argued to be unlikely. Alternatively, the
309 size of the observed effect means that a learning effect or increased desire to perform well
310 on the test cannot be ruled out as confounding factors.

311 Trivial increases and small decreases in UBS in the Pre-PHV and Post-PHV groups were
312 matched by almost identical results in their respective control groups. This suggests that
313 training exerted no effect on this measure, likely due to the nature of the training programme
314 which, based on its configuration, seemed more likely to increase LBS than UBS. This
315 underlines the importance of the specificity of the training stimulus; however, even in
316 interventions that included exercises that targeted the wrist flexors, effects as measured by
317 hand grip strength, were non-existent and small in 1-day (0.0, [-0.5 to 0.5]) and 2-days (0.33
318 [-0.2 to 0.9]) per week training groups (15).

319 The results of this study show that resistance training can enhance VJ performance in both
320 Pre- and Post-PHV swimmers. Despite the pure intervention effect being lower in Pre-PHV,
321 the between-group analysis showed that the effects on VJ were far larger in that group.
322 However, it must be considered that an increase in body weight during Post-PHV could
323 result in greater increases in absolute strength and bodyweight which could result in
324 decreases in relative strength (64) and, thus, a reduced effect on VJ. Research has shown
325 the effects of age, lean leg volume, body mass, altered muscle architecture and
326 neuromuscular coordination on performance in youth (34) and this could partly explain why
327 the Post-PHV group showed larger increases in LBS, which is dependent on absolute
328 strength (37), than in VJ, which is dependent on relative strength (45). Conversely, as
329 hypertrophic gains were less likely to play a role in Pre-PHV, VJ in that group may have

330 been uninhibited by changes in bodyweight and reductions in relative strength. Reinforcing
331 this, Lloyd et al. (33) reported predominantly larger changes in jump height in Pre-PHV youth
332 in response to a variety of different training types, citing maturation-related changes in
333 stretch-shortening cycle regulation as a potential mechanism. Nevertheless, the reader must
334 consider that despite there being a larger post-intervention difference in the Pre-PHV
335 groups, the raw increase in VJ was still greater in the Post-PHV group.

336 It is also important to note that the increases in VJ performance were far less than LBS over
337 the 8 week intervention and plyometric studies of similar duration have reported larger
338 effects on jump performance (42). This underlines the independent nature of different
339 physical qualities (60) and suggests a need to incorporate a range of modalities into training
340 programmes to specifically target multiple abilities. This may be particularly important in
341 Post-PHV (33) when youth seem more receptive to a wider range of training adaptations (42,
342 43). Resistance training has been shown to be effective in increasing jump performance (33,
343 40). However, in many interventions training is carried out alongside sprint or plyometric
344 training meaning that it is difficult to partition the effects of resistance training from those of
345 other modalities. This is further convoluted by many researchers implementing a resistance
346 training program but measuring only its effects on jumping or sprinting performance, and not
347 strength.

348 In terms of resistance training programming, current recommendations for youth are broad
349 (13, 30, 32) and dose responses remain unclear (30). Furthermore, quantifying resistance
350 training loads is a difficult task (30) and several methods have been proposed (10, 35). To
351 establish a basis for comparison with other studies, subjects provided RPEs following each
352 training session. Meylan et al. (40) reported mean RPEs as low as 3.7 ± 1.3 arbitrary units
353 (AU) in light training weeks and as high 6.1 ± 1.5 AUs in heavy training weeks. In
354 comparison, this intervention showed mean RPEs of 6.6 ± 1.0 AUs with little variation over
355 time despite the periodized nature of the training program. In adult males, RPEs of this
356 magnitude have been equated to a mean exercise intensity of around 90% of 1RM across a

357 resistance training session (10), but it remains to be proved if this is directly applicable to a
358 youth population. The reported training RPEs and session-RPEs seem to indicate that
359 training loads across both groups were relatively equal. In future studies, the reporting of
360 RPEs could be a simple, but useful, way of standardizing training loads for comparison
361 across interventions to approximate training intensity in heterogeneous programs. The
362 method has been shown to be reliable in measuring resistance training intensities in adults
363 (10).

364 As highlighted recently (38), research into the trainability of youth must satisfy several
365 criteria such as the inclusion of control groups, the utilization of an assessment of biological
366 maturity status and the direct comparison of responses in different maturity groups. A
367 strength of this study is that it meets all of these criteria and also uses a measure of
368 performance that is specific to the applied training stimulus. Many studies have met one or
369 some of the above criteria but to our knowledge, no previous study achieves all. However, it
370 does have some limitations. Several training studies (4, 17, 49) have used similar statistical
371 methods but with a smaller sample size (<10 subjects) than that recommended by Hopkins
372 (25) such that the sample does not misrepresent the population. In the current study, the
373 Post-PHV training and control groups also have less than 10 subjects potentially limiting the
374 findings' applicability to a wider population. Future research could replicate this study with a
375 larger sample. Also, the randomization of subjects was not possible, though this is also a
376 common drawback in many interventions studies. Mirwald's (41) method of measuring
377 biological maturity status, though reliable, can lack precision. The division made between the
378 maturity groups in the current study was made at the point of 0.0 years to/from PHV
379 meaning that any individual who fell within 6 months proximity to this could have been
380 wrongly categorised. However, as only 3 out of 44 individuals were within this range, it is
381 unlikely that this affected the results to a great extent. Assessments of biological maturity
382 may be reinforced with alternative measures such as that of Khamis and Roche (27) whilst a
383 wider division between groups may also be beneficial in research settings (33, 48). Also,

384 though the performance measures utilised showed clear differences between groups, they
385 do not necessarily explain the underlying mechanisms meaning more research is required.
386 Lastly, though the subjects in the experimental groups were not carrying out another
387 resistance training program, and just two reported informal resistance training experience,
388 many were involved in other sports such as soccer and rugby. This could confound the
389 results and their applicability to other populations, though almost all control subjects were
390 also involved in other sports and did not demonstrate extensive performance changes.

391 Overall, strength and power are trainable to different degrees in Pre-PHV and Post-PHV
392 swimmers but more mature individuals could be more sensitive to applied stimuli potentially
393 owing to a greater contribution from maturational factors.

394 **PRACTICAL APPLICATIONS**

395 The current results advocate the use of 4 compound (1) and core exercises in supporting
396 strength and power (36) in this population. Exercises consisted of 3 sets of 8-12 repetitions
397 (or up to 1 minute on timed exercises) and participants were encouraged to increase
398 repetitions to more challenging ranges when possible. Twice-weekly resistance training
399 sessions of 30 minutes duration is sufficient to provide the necessary stimulus. However,
400 adaptations of Post-PHV youth may be larger than those in Pre-PHV.

401 Less experienced youth can engage in a general programme of integrative neuromuscular
402 training to lay a foundation of technical competency for higher training loads and volumes as
403 they mature. Mature youth who have undergone appropriate foundational training can
404 engage in more advanced training techniques and can be exposed to higher training loads
405 and volumes. Given that Pre-PHV youth may adapt at a lower magnitude, it may be more
406 appropriate to subject them to alternative types of neuromuscular training (12) to yield
407 increases in performance. Such training is considered a prerequisite to further participation
408 in physical activity and is representative of a more focused approach to athletic
409 development. In summary, youth of all ages can engage in resistance training but

410 practitioners may see differences in the magnitude of adaptation across the developmental
411 continuum.

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414 **Conflicts of interest**

415 There are no conflicts of interest.

416 **REFERENCES**

- 417 1. Beardsley C and Contreras B. The increasing role of the hip extensor musculature
418 with heavier compound lower-body movements and more explosive sport actions.
419 *Strength Cond J* 36: 49-55, 2014.
- 420 2. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey M, Lamont H, Hornsby G, Haff
421 G, and Stone M. Relationships of isometric mid-thigh pull variables to weightlifting
422 performance. *J Sports Med Phys Fitness* 53: 573-581, 2013.
- 423 3. Behringer M, Vom Heede A, Matthews M, and Mester J. Effects of strength training
424 on motor performance skills in children and adolescents: a meta-analysis. *Pediatr*
425 *Exerc Sci* 23: 186-206, 2011.
- 426 4. Buchheit M, Mendez-Villanueva A, Quod M, Quesnel T, and Ahmaidi S. Improving
427 acceleration and repeated sprint ability in well-trained adolescent handball players:
428 speed versus sprint interval training. *Int J Sports Physiol Perform* 5: 152-164, 2010.
- 429 5. Cohen DD, Voss C, Taylor MJ, Stasinopoulos DM, Delextrat A, and Sandercock GR.
430 Handgrip strength in English schoolchildren. *Acta Paediatr* 99: 1065-1072, 2010.
- 431 6. Comfort P, Jones PA, McMahon JJ, and Newton R. Effect of knee and trunk angle on
432 kinetic variables during the isometric midhigh pull: test-retest reliability. *Int J Sports*
433 *Physiol Perform* 10: 58-63, 2015.
- 434 7. Comfort P, Stewart A, Bloom L, and Clarkson B. Relationships between strength,
435 sprint, and jump performance in well-trained youth soccer players. *J Strength Cond*
436 *Res* 28: 173-177, 2014.
- 437 8. Dabbs NC, Muñoz CX, Tran TT, and Brown LE. Effect of Rest Interval Following
438 Whole-Body Vibration on Vertical Jump Performance. *J Strength Cond Res* 25: S60-
439 S61, 2011.

- 447
448 9. Dahab KS and McCambridge TM. Strength training in children and adolescents:
449 raising the bar for young athletes? *Sports Health* 1: 223-226, 2009.
- 450
451 10. Day ML, McGuigan MR, Brice G, and Foster C. Monitoring exercise intensity during
452 resistance training using the session RPE scale. *J Strength Cond Res* 18: 353-358,
453 2004.
- 454
455 11. España-Romero V, Artero EG, Santaliestra-Pasias AM, Gutierrez A, Castillo MJ, and
456 Ruiz JR. Hand span influences optimal grip span in boys and girls aged 6 to 12
457 years. *J Hand Surg* 33: 378-384, 2008.
- 458
459 12. Faigenbaum AD, Farrell A, Fabiano M, Radler T, Naclerio F, Ratamess NA, Kang J,
460 and Myer GD. Effects of integrative neuromuscular training on fitness performance in
461 children. *Pediatr Exerc Sci* 23: 573-584, 2011.
- 462
463 13. Faigenbaum AD, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, and
464 Rowland TW. Youth resistance training: updated position statement paper from the
465 national strength and conditioning association. *J Strength Cond Res* 23: S60-S79,
466 2009.
- 467
468 14. Faigenbaum AD, Lloyd RS, MacDonald J, and Myer GD. Citius, Altius, Fortius:
469 beneficial effects of resistance training for young athletes: Narrative review. *Br J*
470 *Sports Med* 50: 3-7, 2016.
- 471
472 15. Faigenbaum AD, Milliken LA, Loud RL, Burak BT, Doherty CL, and Westcott WL.
473 Comparison of 1 and 2 days per week of strength training in children. *Res Q Exercise*
474 *Sport* 73: 416-424, 2002.
- 475
476 16. Faigenbaum AD and Myer GD. Resistance training among young athletes: safety,
477 efficacy and injury prevention effects. *Br J Sports Med* 44: 56-63, 2010.
- 478
479 17. Fernandez-Fernandez J, Sanz-Rivas D, Kovacs MS, and Moya M. In-season effect
480 of a combined repeated sprint and explosive strength training program on elite junior
481 tennis players. *J Strength Cond Res* 29: 351-357, 2015.
- 482
483 18. Folland JP and Williams AG. Morphological and neurological contributions to
484 increased strength. *Sports Med* 37: 145-168, 2007.
- 485
486 19. Foster C, Daines E, Hector L, Snyder AC, and Welsh R. Athletic performance in
487 relation to training load. *Wis Med J* 95: 370-374, 1996.
- 488
489 20. Franco-Márquez F, Rodríguez-Rosell D, González-Suárez J, Pareja-Blanco F, Mora-
490 Custodio R, Yañez-García J, and González-Badillo J. Effects of combined resistance
491 training and plyometrics on physical performance in young soccer players. *Int J*
492 *Sports Med* 36: 906-914, 2015.

- 493
494 21. Gonzalez-Badillo JJ, Pareja-Blanco F, Rodriguez-Rosell D, Abad-Herencia JL, Del
495 Ojo-Lopez JJ, and Sanchez-Medina L. Effects of velocity-based resistance training
496 on young soccer players of different ages. *J Strength Cond Res* 29: 1329-1338,
497 2015.
- 498
499 22. Hara M, Shibayama A, Takeshita D, Hay DC, and Fukashiro S. A comparison of the
500 mechanical effect of arm swing and countermovement on the lower extremities in
501 vertical jumping. *Hum Mov Sci* 27: 636-648, 2008.
- 502
503 23. Hopkins W. A Spreadsheet for Deriving a Confidence Interval, Mechanistic Inference
504 and Clinical Inference from a P Value. *Sportscience* 11: 16-20, 2007.
- 505
506 24. Hopkins W, Marshall S, Batterham A, and Hanin J. Progressive statistics for studies
507 in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.
- 508
509 25. Hopkins WG. Estimating Sample Size for Magnitude-Based Inferences.
510 *Sportscience*: 63-70, 2006.
- 511
512 26. Kelleher AR, Hackney KJ, Fairchild TJ, Kestacy S, and Ploutz-Snyder LL. The
513 metabolic costs of reciprocal supersets vs. traditional resistance exercise in young
514 recreationally active adults. *J Strength Cond Res* 24: 1043-1051, 2010.
- 515
516 27. Khamis HJ and Roche AF. Predicting adult stature without using skeletal age: the
517 Khamis-Roche method. *Pediatrics* 94: 504-507, 1994.
- 518
519 28. Kibele A and Behm DG. Seven weeks of instability and traditional resistance training
520 effects on strength, balance and functional performance. *J Strength Cond Res* 23:
521 2443-2450, 2009.
- 522
523 29. Knuttgen HG and Komi PV. Basic Considerations for Exercise, in: *Strength and*
524 *Power in Sport*. P Komi, ed. Oxford: Blackwell Science Ltd, 2003.
- 525
526 30. Lesinski M, Prieske O, and Granacher U. Effects and dose-response relationships of
527 resistance training on physical performance in youth athletes: a systematic review
528 and meta-analysis. *Br J Sports Med* doi:10.1136/bjsports-2015-095497: In Press,
529 2016.
- 530
531 31. Lillegard WA, Brown EW, Wilson DJ, Henderson R, and Lewis E. Efficacy of strength
532 training in prepubescent to early postpubescent males and females: effects of gender
533 and maturity. *Pediatr Rehabil* 1: 147-157, 1997.
- 534
535 32. Lloyd RS, Faigenbaum AD, Stone MH, Oliver JL, Jeffreys I, Moody JA, Brewer C,
536 Pierce KC, McCambridge TM, and Howard R. Position statement on youth resistance
537 training: the 2014 International Consensus. *Br J Sports Med*: bjsports-2013-092952,
538 2013.

- 539
540 33. Lloyd RS, Radnor JM, De Ste Croix MB, Cronin JB, and Oliver JL. Changes in Sprint
541 and Jump Performances After Traditional, Plyometric, and Combined Resistance
542 Training in Male Youth Pre- and Post-Peak Height Velocity. *J Strength Cond Res* 30:
543 1239-1247, 2016.
- 544
545 34. Martin RJ, Dore E, Twisk J, van Praagh E, Hautier CA, and Bedu M. Longitudinal
546 changes of maximal short-term peak power in girls and boys during growth. *Med Sci*
547 *Sports Exerc* 36: 498-503, 2004.
- 548
549 35. McBride JM, McCaulley GO, Cormie P, Nuzzo JL, Cavill MJ, and Triplett NT.
550 Comparison of methods to quantify volume during resistance exercise. *J Strength*
551 *Cond Res* 23: 106-110, 2009.
- 552
553 36. McGill S. Core training: Evidence translating to better performance and injury
554 prevention. *Strength Cond J* 32: 33-46, 2010.
- 555
556 37. McGuigan MR and Winchester JB. The relationship between isometric and dynamic
557 strength in college football players. *J Sports Sci Med* 7: 101-105, 2008.
- 558
559 38. McNarry MA, Lloyd RS, Buchheit M, Williams CA, and Oliver JL. The BASES Expert
560 Statement on Trainability during Childhood and Adolescence. *Sport Exerc Sci* 4: 22-
561 23, 2014.
- 562
563 39. McNeal JR and Sands WA. Acute static stretching reduces lower extremity power in
564 trained children. *Pediatr Exerc Sci* 15: 139-145, 2003.
- 565
566 40. Meylan CM, Cronin JB, Oliver JL, Hopkins WG, and Contreras B. The effect of
567 maturation on adaptations to strength training and detraining in 11-15-year-olds.
568 *Scand J Med Sci Sports* 24: e156-164, 2014.
- 569
570 41. Mirwald RL, Baxter-Jones AD, Bailey DA, and Beunen GP. An assessment of
571 maturity from anthropometric measurements. *Med Sci Sports Exerc* 34: 689-694,
572 2002.
- 573
574 42. Moran J, Sandercock GRH, Ramírez-Campillo R, Meylan CM, Collison J, and Parry
575 DAP. Age-related variation in male youth athletes' countermovement jump following
576 plyometric training: a meta-analysis of controlled trials. *J Strength Cond Res*: In
577 Press, 2016.
- 578
579 43. Moran J, Sandercock GRH, Ramírez-Campillo R, Meylan CM, Collison J, and Parry
580 DAP. A meta-analysis of maturation-related variation in adolescent boy athletes'
581 adaptations to short-term resistance training *J Sport Sci*: In Press, 2016.
- 582

- 583 44. Naughton G, Farpour-Lambert NJ, Carlson J, Bradney M, and Van Praagh E.
584 Physiological issues surrounding the performance of adolescent athletes. *Sports Med*
585 30: 309-325, 2000.
- 586
587 45. Nuzzo JL, McBride JM, Cormie P, and McCaulley GO. Relationship between
588 countermovement jump performance and multijoint isometric and dynamic tests of
589 strength. *J Strength Cond Res* 22: 699-707, 2008.
- 590
591 46. Ortega FB, Artero EG, Ruiz JR, Vicente-Rodriguez G, Bergman P, Hagströmer M,
592 Ottevaere C, Nagy E, Konsta O, and Rey-Lopez J. Reliability of health-related
593 physical fitness tests in European adolescents. The HELENA Study. *Int J Obes* 32:
594 S49-S57, 2008.
- 595
596 47. Pfeiffer RD and Francis RS. Effects of Strength Training on Muscle Development in
597 Prepubescent, Pubescent, and Postpubescent Males. *Phys Sportsmed* 14: 134-139,
598 1986.
- 599
600 48. Radnor JM, Lloyd RS, and Oliver JL. Individual Response To Different Forms Of
601 Resistance Training In School Aged Boys. *J Strength Cond Res*: In Press, 2016.
- 602
603 49. Ramirez-Campillo R, Henriquez-Olguin C, Burgos C, Andrade D, Zapata D, Martinez
604 C, Alvarez C, Baez EI, Castro-Sepulveda M, Penailillo L, and Izquierdo M. Effect of
605 Progressive Volume-Based Overload during Plyometric Training on Explosive and
606 Endurance Performance in Young Soccer Players. *J Strength Cond Res* 29: 1884-
607 1193, 2014.
- 608
609 50. Ramsay JA, Blimkie CJ, Smith K, Garner S, MacDougall JD, and Sale DG. Strength
610 training effects in prepubescent boys. *Med Sci Sports Exerc* 22: 605-614, 1990.
- 611
612 51. Rhea MR. Determining the magnitude of treatment effects in strength training
613 research through the use of the effect size. *J Strength Cond Res* 18: 918-920, 2004.
- 614
615 52. Rodriguez-Rosell D, Franco-Marquez F, Pareja-Blanco F, Mora-Custodio R, Yáñez-
616 García J, González-Suárez J, and González-Badillo J. Effects of 6-Weeks
617 Resistance Training Combined With Plyometric and Speed Exercises on Physical
618 Performance of Pre-Peak Height Velocity Soccer Players. *Int J Sports Physiol*
619 *Perform* 11: 240-246, 2016.
- 620
621 53. Rumpf MC, Cronin JB, Mohamad IN, Mohamad S, Oliver JL, and Hughes MG. The
622 effect of resisted sprint training on maximum sprint kinetics and kinematics in youth.
623 *Eur J Sport Sci* 15: 374-381, 2015.
- 624
625 54. Rumpf MC, Cronin JB, Pinder SD, Oliver J, and Hughes M. Effect of different training
626 methods on running sprint times in male youth. *Pediatr Exerc Sci* 24: 170-186, 2012.
- 627

- 628 55. Santos EJ and Janeira MA. Effects of complex training on explosive strength in
629 adolescent male basketball players. *J Strength Cond Res* 22: 903-909, 2008.
- 630
631 56. Spencer M, Fitzsimons M, Dawson B, Bishop D, and Goodman C. Reliability of a
632 repeated-sprint test for field-hockey. *J Sci Med Sport* 9: 181-184, 2006.
- 633
634 57. Thomas C, Mather D, and Comfort P. Changes in sprint, change of direction and
635 jump performance during a competitive season in male lacrosse players. *J Athl
636 Enhanc* 3: 1-8, 2014.
- 637
638 58. Thompson A and Taylor BN. B.8 Factors for Units Listed Alphabetically.
639 <http://physics.nist.gov/Pubs/SP811/appenB8.html#K> Accessed Sep 23, 2016/.
- 640
641 59. Till K, Cobley S, O' Hara J, Cooke C, and Chapman C. Considering maturation status
642 and relative age in the longitudinal evaluation of junior rugby league players. *Scand J
643 Med Sci Sports* 24: 569-576, 2014.
- 644
645 60. Vissing K, Brink M, Lonbro S, Sorensen H, Overgaard K, Danborg K, Mortensen J,
646 Elstrom O, Rosenhoj N, Ringgaard S, Andersen JL, and Aagaard P. Muscle
647 adaptations to plyometric vs. resistance training in untrained young men. *J Strength
648 Cond Res* 22: 1799-1810, 2008.
- 649
650 61. Vrijens J. Muscle strength development in the pre-and post-pubescent age. *Med
651 Sport Sci* 11: 152-158, 1978.
- 652
653 62. Waugh CM, Korff T, Fath F, and Blazevich AJ. Effects of resistance training on
654 tendon mechanical properties and rapid force production in prepubertal children. *J
655 Appl Physiol* 117: 257-266, 2014.
- 656
657 63. Wrigley RD, Drust B, Stratton G, Atkinson G, and Gregson W. Long-term soccer-
658 specific training enhances the rate of physical development of academy soccer
659 players independent of maturation status. *Int J Sports Med* 35: 1090-1094, 2014.
- 660
661 64. Zatsiorsky V and Kraemer W. *Science and practice of strength training*. Champaign:
662 Human Kinetics, 2006.
- 663
664

Table 1 Descriptive data for participants

Pre-PHV Group	Experimental (n = 14)	Control (n = 15)	Effect size
Age (years)	11.9 ± 1.2	11.3 ± 1.2	0.5 (-0.1 to 1.1) _{small}
Age range (years)	10.4-13.2	9.6-13.9	
Maturity offset (years)	-1.8 ± 1.0	-2.0 ± 1.1	0.2 (-0.4 to 0.8) _{trivial}
Height (cm)	152.5 ± 6.6	152.4 ± 12.1	0.0 (-0.6 to 0.6) _{trivial}
Sitting height (cm)	75.2 ± 4.4	75.5 ± 5.6	-0.1 (-0.7 to 0.6) _{trivial}
Mass (kg)	44.7 ± 10.0	47.4 ± 13.3	-0.2 (-0.8 to 0.4) _{small}
Post-PHV Group	Experimental (n = 8)	Control (n = 7)	Effect size
Age (years)	15.0 ± 1.1	14.9 ± 1.2	0.1 (-0.8 to 0.9) _{trivial}
Age range (years)	15.4-17.0	14.7-17.5	
Maturity offset (years)	1.6 ± 0.5	1.2 ± 1.0	0.5 (-0.3 to 1.4) _{small}
Height (cm)	176.4 ± 3.6	173.9 ± 6.5	0.5 (-0.4 to 1.3) _{small}
Sitting height (cm)	89.9 ± 2.5	87.1 ± 3.7	0.9 (0.0 to 1.8) _{moderate}
Mass (kg)	68.5 ± 5.6	66.4 ± 9.7	0.3 (-0.6 to 1.1) _{small}

Table 2 Resistance training programme

Phase 1	Week 1		Week 2		Week 3		Week 4	
	Sets	Repetitions	Sets	Repetitions	Sets	Repetitions	Sets	Repetitions
Goblet squats	3	8	3	10	3	12	3	max
Push ups	3	8	3	10	3	12	3	max
Supine weighted hip thrusts	3	8	3	10	3	12	3	max
Side planks	3	15 secs e/s	3	20 secs e/s	3	20 secs e/s	3	30 secs e/s
Rest	2-3 mins following continuous execution of all four exercises w/mobility work		2-3 mins following continuous execution of all four exercises w/mobility work		2-3 mins following continuous execution of all four exercises w/mobility work		2-3 mins following continuous execution of all four exercises w/mobility work	
Phase 2	Week 5		Week 6		Week 7		Week 8	
	Sets	Repetitions	Sets	Repetitions	Sets	Repetitions	Sets	Repetitions
Goblet split squats	3	8 e/s	3	10 e/s	3	12 e/s	3	max e/s
Push ups	3	10	3	12	3	max	3	max
Supine isometric weighted hip thrusts	3	45 secs	3	60 secs	3	75 secs	3	90 secs
Spiderman planks	3	6 e/s	3	8 e/s	3	10 e/s	3	12 e/s
Rest	2-3 mins following continuous execution of all four exercises w/mobility work		2-3 mins following continuous execution of all four exercises w/mobility work		2-3 mins following continuous execution of all four exercises w/mobility work		2-3 mins following continuous execution of all four exercises w/mobility work	

e/s: each side

Variable	Group	Baseline (SD)	Follow-up (SD)	Effect size	Confidence limits	Likelihood effect is beneficial	Effect description	Odds ratio of benefit to harm
Mid-thigh pull (kgf)	All (Experimental)	94.9 (35.1)	115.6 (38.3)	0.6	0.1 to 1.1	86.1%	Small increase	407
	All (Control)	87.0 (32.8)	96.1 (33.3)	0.3	-0.2 to 0.8	67.9%	Small increase	576
	Pre-PHV Experimental	74.0 (20.7)	92.5 (26.4)	0.8	0.1 to 1.4	89.5%	Moderate increase	374
	Pre-PHV Control	78.2 (30.2)	82.0 (28.1)	0.1	-0.5 to 0.7	18.1%	Trivial increase	828
	Post-PHV Experimental	131.3 (22.6)	156.0 (13.1)	1.3	0.4 to 2.2	92.4%	Large increase	359
	Post-PHV Control	105.9 (32.1)	126.4 (21.8)	0.7	-0.2 to 1.7	89.8%	Moderate increase	350
Hand grip (kgf)	All (Experimental)	27.8 (10.6)	27.6 (9.8)	0.0	-0.5 to 0.5	0.0%	Trivial decrease	0
	All (Control)	24.8 (9.0)	25.0 (7.7)	0.0	-0.5 to 0.5	0.0%	Trivial increase	43
	Pre-PHV Experimental	20.9 (4.8)	21.7 (5.1)	0.2	-0.5 to 0.8	34.0%	Trivial increase	636
	Pre-PHV Control	20.3 (5.4)	21.2 (5.3)	0.2	-0.4 to 0.8	37.2%	Trivial increase	677
	Post-PHV Experimental	39.9 (5.6)	37.9 (6.7)	-0.3	-1.2 to 0.5	0.9%	Small decrease	0
	Post-PHV Control	34.5 (7.3)	33.1 (5.6)	-0.2	-1.1 to 0.7	0.5%	Small decrease	0
Vertical jump (cm)	All (Experimental)	37.3 (6.8)	38.8 (7.1)	0.2	-0.3 to 0.7	56.9%	Small increase	713
	All (Control)	32.9 (6.2)	32.0 (7.4)	-0.1	-0.6 to 0.4	0.0%	Trivial decrease	0
	Pre-PHV Experimental	35.6 (7.0)	36.8 (7.3)	0.2	-0.5 to 0.8	37.0%	Trivial increase	620

Pre-PHV Control	30.7 (5.4)	28.9 (5.4)	-0.3	-0.9 to 0.3	0.7%	Small decrease	0
Post-PHV Experimental	40.1 (5.7)	42.4 (5.4)	0.4	-0.4 to 1.2	82.0%	Small increase	344
Post-PHV Control	37.6 (5.6)	38.6 (7.1)	0.2	-0.7 to 1.0	30.4%	Trivial increase	196

Table 3 Within-group analysis baseline and follow-up scores, percentage change, effect sizes, confidence limits, likelihood effects and odds ratios for performance data

Variable	Comparison	Effect size	Confidence limits	Likelihood effect is beneficial	Effect description	Odds ratio of benefit to harm
Mid-thigh pull (kgf)	Experimental vs. Control (All)	0.5	0.0 to 1.0	85.5%	Small increase	411
	Experimental vs. Control (Pre-PHV)	0.4	-0.2 to 1.0	79.0%	Small increase	486
	Experimental vs. Control (Post-PHV)	1.7	0.7 to 2.7	92.9%	Large increase	364
Hand grip (kgf)	Experimental vs. Control (All)	0.3	-0.2 to 0.8	71.4%	Small increase	540
	Experimental vs. Control (Pre-PHV)	0.1	-0.5 to 0.7	3.8%	Trivial increase	5092
	Experimental vs. Control (Post-PHV)	0.8	-0.1 to 1.7	89.4%	Moderate increase	374
Vertical jump (cm)	Experimental vs. Control (All)	0.9	0.4 to 1.5	90.5%	Moderate increase	377
	Experimental vs. Control (Pre-PHV)	1.2	0.6 to 1.9	91.8%	Large increase	372
	Experimental vs. Control (Post-PHV)	0.6	-0.3 to 1.5	87.2%	Moderate increase	383

Table 4 Between-group analysis effect sizes, confidence limits, likelihood effects and odds ratios for performance data

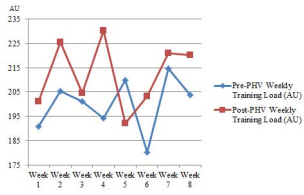
Table 5 Descriptive data for training load

	All	Pre-PHV	Post-PHV	Effect size
Mean session duration (mins)	31.0 ± 3.2	31.0 ± 3.1	30.9 ± 3.3	0.0 (-0.8 to 0.7) _{trivial}
Mean RPE	6.6 ± 1.0	6.5 ± 1.1	6.9 ± 0.9	0.4 (-0.3 to 1.1) _{small}
Mean session load (AU)	204.8 ± 38.0	200.4 ± 38.1	212.8 ± 36.6	0.3 (-0.4 to 1.1) _{small}
Mean attendance (%)	89.2 ± 7.8	89.7 ± 8.7	88.3 ± 6.2	-0.2 (-0.9 to 0.6) _{trivial}

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