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A COMARISON OF PRE-SEASON AND IN-SEASON PRACTICE AND GAME LOADS IN NCAA DIVISION I FOOTBALL PLAYERS

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6 Authors:

7 Aaron D. Wellman¹, Sam C. Coad¹, Patrick J. Flynn², Ty K. Siam³, Christopher P. McLellan¹

8 ¹ Faculty of Health Sciences and Medicine, Bond University, Queensland, Australia.

9 ² School of Computer Science and Engineering, University of Notre Dame, Notre Dame, IN.

10 ³ Football Operations Analyst, New York Giants, East Rutherford, NJ.

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12 Contact Information

Aaron Wellman

13

Bond University

14

14 University Dr

15

Robina QLD 4226, Australia

16

Email: aaron.wellman@giants.nfl.net

17

Phone : (201) 578-4456

18

19 Research Laboratory:

Bond University Institute of Health and Sport, Bond University,

20

Queensland, Australia.

21

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29 **ABSTRACT**

30

31 The aim of the present study was to quantify the individual practice and game loads
32 throughout an NCAA division I football season to determine if significant differences
33 exist between the practice loads associated with pre-season training camp and those
34 undertaken during the in-season period. Thirty-one NCAA division I football players
35 were monitored using GPS and IA (MinimaxX S5; Catapult Innovations, Melbourne,
36 Australia) during 22 pre-season practices, 36 in-season practices, and 12 competitions.
37 The season was divided into four distinct phases for data analysis: pre-season week 1
38 (pre-season1), pre-season week 2 (pre-season2), pre-season week 3 (pre-season3),
39 and 12 in-season weeks. Individual IA datasets represented players from every
40 offensive and defensive position group (WR: n=5), (OL: n=4), (RB: n=4), (QB: n=2), (TE:
41 n=3), (DL: n=4), (LB: n=4), (DB: n=5). Data were set at the practice level, where an
42 observation for each player's maximum player load (PLMax) or mean player load
43 (PLMean) from each training camp phase was referenced against each player's
44 respective PL from each game, Tuesday, Wednesday, or Thursday practice session.
45 Notable results included significantly ($p<0.05$) greater PLMax values attributed to pre-
46 season1 compared to PL resulting from all in-season practices, and significantly
47 ($p<0.05$) higher cumulative PL reported for pre-season1, 2, and 3 compared to every in-
48 season week. Data from the present study augment our understanding of the practice
49 demands experienced by NCAA division I college football players, and provide scope

50 for the improvement of pre-season practice design and physical conditioning strategies
51 for coaches seeking to optimize performance.

52

53 **Key Words:** Integrated Accelerometers, monitoring, American football

54

55 **INTRODUCTION**

56

57 American football is a full-contact team sport characterized by high-speed running and
58 frequent accelerations, decelerations, change of direction specific impacts, and blunt
59 force trauma resulting from repeated contact with opponents and the ground during
60 blocking, tackling, and ball carrying (27,28,29). Recent studies (28,29) have provided
61 novel insight to the positional movement demands associated with NCAA division I
62 football, including the quantification of sprint distances and high-intensity accelerations
63 and decelerations, and the frequency and intensity of positional impacts and rapid
64 changes of direction associated with competition. Global positioning system (GPS)
65 derived positional movement demands of NCAA division I football players during
66 competition (28) and pre-season training camp (7) have been reported, however data
67 describing the daily physical demands of the in-season period in college football, remain
68 unestablished.

69

70 Global positioning systems technology with integrated triaxial accelerometers (IA) have
71 provided a means of quantifying the physical demands of training and competition in
72 contact team sports (10,21,28). Improvements in technology and sampling
73 methodologies have increased the accuracy of data recorded via portable GPS and IA

74 for applied research purposes (17), and have provided a valid and reliable means of
75 assessing activity profiles in team sports (5,18). Additionally, IA have demonstrated
76 reliability (2) as a means of measuring physical activity across multiple players in team
77 sports, with strong inter-unit relationships ($r=0.996-0.999$) demonstrated during high-
78 intensity contact team sport activity.

79

80 College football teams generally participate in an intensified pre-season training camp
81 that typically consists of a maximum of 29 practice sessions performed over a period of
82 approximately 4-5 weeks prior to the first competitive event of the season (24). Pre-
83 season training camp traditionally involves programming loads that are developed to
84 maximize positive physical adaptation and minimize maladaptation that may be
85 associated with acute and cumulative fatigue, presenting logistical and player
86 management challenges for coaches and performance staff. Despite an increased
87 understanding of the positional movement demands associated with competition and
88 pre-season training camp practices, the daily physical demands associated with
89 practices during the in-season competitive period remain unknown. A more
90 comprehensive understanding of the daily physical demands associated with the in-
91 season competitive period will augment our understanding of the demands of NCAA
92 football players and provide scope for improvements in the planning of pre-season
93 training camp practices to adequately prepare players for the demands of the in-season
94 period. The aim of the present study was to quantify the individual practice and game
95 loads throughout an NCAA division I football season to determine if significant
96 differences exist between the training loads associated with pre-season training camp

97 and those undertaken during the in-season competitive period. We hypothesize that
98 there will be significant differences in training loads associated with pre-season training
99 camp when compared to the in-season competitive period in NCAA division I football
100 players.

101

102 **METHODS**

103

104 **EXPERIMENTAL APPROACH TO THE PROBLEM**

105

106 To examine practice session training loads during the in-season and pre-season
107 periods of an NCAA division I football season, portable IA data were collected from
108 players during 22 pre-season training camp practices, 36 regular season practices, and
109 12 competitions, completed between August 7 and November 28. The individual IA
110 datasets in the present study represented subjects from all offensive and defensive
111 position groups as follows: (WR: n=5), (OL: n=4), (RB: n=4), (QB: n=2), (TE: n=3), (DL:
112 n=4), (LB: n=4), (DB: n=5) . To determine inter-week PL differentials, each practice and
113 game completed was assessed as a single observation.

114

115 **SUBJECTS**

116

117 Thirty-one National Collegiate Athletic Association (NCAA) Division I Football Bowl
118 Subdivision (FBS) football players (age 20.5 ± 1.1 years; age range 18.6 – 22.9; height
119 187.6 ± 6.2 cm; and mass 106.8 ± 18.6 kg) participated in the present study. All

120 subjects were collegiate athletes whom had been selected to participate in the football
121 program prior to the commencement of the study. All participants in the present study
122 completed the teams' 8-week summer off-season physical development training
123 program that included a full-body strength and power training program and specific skills
124 and conditioning sessions designed to simulate the demands of NCAA division I college
125 football practice. The present study comprises the statistical analysis of data collected
126 as part of the day to day student athlete monitoring and testing procedures within the
127 university's football program. Ethical approval was obtained from the university's
128 Institutional Review Board and all subjects signed an institutionally approved informed
129 consent document prior to participating in the study.

130

131 PROCEDURES

132

133 *Global Positioning System Units.* Positional movement data were collected from 22 pre-
134 season practice sessions, 36 in-season practice sessions and 12 games using
135 commercially available microtechnology units (MinimaxX S5; Catapult Innovations,
136 Melbourne, Australia). The units included a triaxial accelerometer (IA) which operated
137 at 100 Hz and assessed the frequency and magnitude of full-body acceleration
138 ($\text{m}\cdot\text{second}^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical
139 (19,20). Prior to the commencement of each practice and game, GPS receivers were
140 placed outside for 15 minutes to acquire a satellite signal, after which, receivers were
141 placed in a custom designed pocket attached to the shoulder pads of the subjects.
142 Shoulder pads were custom-fit for each individual, thereby minimizing movement of the

143 pads during practices. The GPS and IA receivers used in the present study were
144 positioned in the center of the upper back, slightly superior to the scapulae. Subjects
145 were outfitted with the same GPS receiver for each practice and game. Following the
146 completion of practices, GPS receivers were removed from the shoulder pads, and
147 subsequently downloaded to a computer for analysis utilizing commercially available
148 software (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia). In the
149 present study, training load was determined via combined tri-axial accelerometer data
150 and represented as PlayerLoad™ (PL), which is a modified vector magnitude expressed
151 as the square root of the sum of the squared instantaneous rates of change in
152 acceleration in each of the three planes and divided by 100 (2). Previous research has
153 documented a strong correlation between PL and total distance in Australian football (r
154 = 0.97, 95% CI: 0.96 – 0.98) (12). Boyd and colleagues (2) have demonstrated the
155 laboratory intra-unit (0.91-1.05 % coefficient of variation [CV]) and inter-unit (1.02-1.10
156 % CV) reliability of PL and determined its inter-unit reliability in Australian Rules Football
157 matches (1.90% CV). Findings from other team sports including basketball, netball, and
158 Australian football have demonstrated the ability of accelerometer derived PL to
159 differentiate between competitive games, scrimmage games, practice drills, positional
160 demands, and levels of competition (1,3,22). The GPS and IA units utilized in the
161 present study have demonstrated the ability to accurately detect collisions associated
162 with contact team-sport participation (9,15). Collision events identified by
163 microtechnology devices during rugby league match-play demonstrated a strong
164 positive correlation with video coded collision events ($r=0.96$), with no difference
165 between the number of collisions identified by microtechnology and video coding, and

166 were sensitive to detect 97.6% of collisions that occurred (15). Previous research by
167 Gabbett et. al. (9) has also demonstrated the ability of the GPS and IA units utilized in
168 the present study to accurately identify collision events against video-based coding of
169 actual collision events ($r = 0.96$, $p < 0.01$).

170

171 *Phases of Season.* For data analysis, the season was divided into four distinctive
172 phases, namely pre-season week 1 (pre-season1), pre-season week 2 (pre-season2),
173 pre-season week 3 (pre-season3), and 12 in-season weeks. Each week was
174 represented as seven calendar days, and the number of practice sessions included for
175 each pre-season practice week included: 8 for pre-season1 (3 full pads, 3 shoulder
176 pads and helmet, 2 helmets only), 8 for pre-season2 (6 full pads and 2 shoulder pads
177 and helmets), and 6 for pre-season3 (6 full pads). Two practices occurred on three
178 separate days, namely days 6, 8, and 13 of pre-season training camp. Each in-season
179 week consisted of a Tuesday, Wednesday, and a Thursday practice session, in addition
180 to a game each Saturday.

181

182 **STATISTICAL ANALYSES**

183

184 The present study quantifies the relative PL differential in NCAA division I college
185 football players between three phases of training camp, in-season games, and
186 Tuesday, Wednesday, and Thursday practice sessions. Data were set at the practice
187 level, where an observation for each player's maximum player load (PLMax) session
188 from each training camp phase, or the mean player load (PLMean) across each training

189 camp phase, was referenced against each player's respective PL resulting from each
190 game, and Tuesday, Wednesday, or Thursday practice session, for each week
191 throughout the season. Additionally, a model was run examining the cumulative PL for
192 each week from pre-season1 through the end of the competitive season. Nine OLS
193 regressions, utilizing a control for each individual player, were used to determine the
194 roster-level variation for in-season practices and games compared to each phase of
195 training camp. Each model examined the in-season PL from a Tuesday, Wednesday,
196 Thursday, or Game session against either the maximum player load achieved in each of
197 the three phases of training camp, or the average player load across all sessions from
198 each phase of training camp. Standard errors were clustered at the individual level due
199 to the nested structure of the data throughout the season. Following completion of the
200 regressions, post-hoc t-tests and pair-wise comparisons were used to establish inter-
201 week significance for PL variation. Adjusted means for each training camp phase and
202 in-season week are reported for each model in tables 1 and 2. Alpha intervals for all
203 hypothesis testing were set at $p < 0.05$ as the level of significance for statistical tests.
204 All statistical analyses were performed using Stata Statistical/Data Analysis Software
205 (Stata 14 for Windows, version 14.1; StataCorp, College Station, TX, USA).

206

207 The inclusion criteria for the Tuesday, Wednesday, and Thursday models was full
208 participation in a session, thus all observations where a player participated fully were
209 used. In the case of unit malfunctions where an individual participated fully, player load
210 was imputed for individuals based on their unique average for that type of session,
211 which occurred on seven instances throughout the study. The inclusion criteria for the

212 game day model was participation in $\geq 75\%$ of the offensive or defensive plays, while the
213 inclusion criteria for the cumulative PL model was full participation in all sessions in that
214 given week. Thirty-one players were eligible for the present study.

215

216 **RESULTS**

217

218 Several significant differences in PLMax (Table 1) and PLMean (Table 2) between pre-
219 season training camp practices and in-season practice sessions were reported.

220 Maximum and Mean PL were significantly ($p < 0.05$) lower in pre-season2 and pre-
221 season3 compared to pre-season1. Every in-season Tuesday practice session resulted
222 in significantly ($p < 0.05$) lower PL than the PLMax achieved in pre-season1.

223 Additionally, Tuesday practice sessions in weeks 1-3 and 9-12 demonstrated
224 significantly ($p < 0.05$) lower PL than the PLMax reported in pre-season2 and pre-
225 season3. Wednesday and Thursday practices from every in-season week, except in-
226 season week 5, resulted in significantly ($p < 0.05$) lower PL than the PLMax

227 demonstrated in pre-season1, 2, and 3. Five games exhibited significantly ($p < 0.05$)
228 lower PL than the PLMax reported in pre-season1, one game resulted in significantly
229 ($p < 0.05$) higher PL than the PLMax in pre-season1, while the remaining 6 games
230 demonstrated no significant ($p < 0.05$) differences than the PLMax in pre-season1.

231

232

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234

235 An examination of PLMean resulting from pre-season training camp demonstrated
236 significantly ($p<0.05$) greater PLMean in pre-season1 than all in-season Wednesday
237 and Thursday practice sessions, and 9 out of 12 Tuesday practice sessions. The in-
238 season week 1 Tuesday practice session PL was significantly ($p<0.05$) lower than the
239 PLMean in pre-season1, 2 and 3, while Tuesday practice sessions in weeks 2-8
240 demonstrated significantly ($p<0.05$) higher PL than the PLMean reported in pre-season2
241 and 3. No significant ($p<0.05$) differences were established between Tuesday practice
242 sessions in weeks 9-12 and those demonstrated in pre-season2 and 3. Four in-season
243 Wednesday practices resulted in significantly ($p<0.05$) higher PL than PLMean in pre-
244 season2, while another four Wednesday practices resulted in significantly ($p<0.05$)
245 lower PL than the PLMean in pre-season2. All Thursday practice sessions were
246 associated with significantly ($p<0.05$) lower PL than the PLMean reported for pre-
247 season2 and 3. Ten out of twelve games resulted in significantly ($p<0.05$) higher PL
248 than the PLMean demonstrated in pre-season1, while all games were associated with
249 significantly ($p<0.05$) higher PL than the PLMean achieved in pre-season2 and 3.
250
251
252 The cumulative PL (Table 2) resulting from pre-season1 was significantly ($p<0.05$)
253 greater than that of pre-season2 and 3, and the cumulative PL in pre-season2 was
254 significantly greater than that of pre-season3. All pre-season weeks demonstrated
255 significantly ($p<0.05$) higher cumulative PL than the cumulative PL resulting from all 12
256 in-season weeks.
257

258 **Insert Tables 1 and 2 here**

259

260 The average and maximum session duration for pre-season1, pre-season2, pre-
261 season3, Tuesday, Wednesday, and Thursday practice sessions, in addition to average
262 and maximum game durations, are described in Table 3.

263

264 **Insert Table 3 here**

265

266 **DISCUSSION**

267

268 The aim of the present study was to quantify the individual practice and game loads
269 throughout an NCAA division I football season to determine if significant differences
270 exist between the training loads associated with pre-season training camp and those
271 undertaken during the in-season competitive period. The results of the present study
272 contribute novel insight into the practice and competitive loads experienced by NCAA
273 division I college football players throughout the pre-season and in-season periods, and
274 provide scope for the programming of pre-season practices and the design of physical
275 conditioning strategies to prepare athletes for the rigors of pre-season training camp.

276 The results confirm our hypothesis that significant differences in training loads
277 associated with pre-season training camp, when compared to the in-season competitive
278 period in NCAA division I football players, exist. The most notable findings were the
279 significantly ($p<0.05$) greater PLMax values attributed to pre-season1 compared to PL
280 resulting from all in-season practices, and the significantly ($p<0.05$) higher cumulative

281 PL reported for pre-season1, 2, and 3 compared to the cumulative PL for every in-
282 season week.

283

284 In the present study, pre-season1 resulted in significantly ($P<0.05$) higher PLMax and
285 PLMean values than both pre-season2 and pre-season3. The PLMax achieved in the
286 first week of pre-season camp was significantly ($p<0.05$) higher than the PL resulting
287 from 42% of games, and all Tuesday, Wednesday, and Thursday practice sessions
288 throughout the in-season period. The PLMean resulting from pre-season1 was
289 significantly ($p<0.05$) higher than PL values of all Wednesday and Thursday practices,
290 nine of twelve Tuesday practice sessions, and two games. These data clearly
291 demonstrate that pre-season1 exposed players to the highest PL of the pre-season and
292 in-season practice period, in addition to significantly ($p<0.05$) higher PL than 5 out of 12
293 games. Indeed, only one game was associated with a significantly ($p<0.05$) higher PL
294 than the PLMax achieved in pre-season1. Collectively, these data contrast training
295 load progression recommendations provided to mitigate injury risk (16) and optimize
296 athlete preparation prior to the commencement of the NCAA division I football season.

297

298 It is widely understood that the appropriate planning of single and multi-day pre- and in-
299 season training sessions is a fundamental aspect of optimal performance, however
300 limited data exists to support a specific approach to programming training sessions in
301 team sports (23). Comparing the results of the present study with previous
302 examinations is problematic due to the lack of similar investigations in NCAA division I
303 football. Previous investigations in Australian football have reported increased training

304 loads and training session duration in the pre-season period when compared to the in-
305 season competitive period (23,26). While similarities may exist between Australian
306 football and NCAA division I college football, direct comparisons between the pre-
307 season periods in each of these sports is problematic, most notably due to the duration
308 of the pre-season period in Australian football, often lasting more than 20 weeks (23),
309 while college football pre-season practice takes place over approximately four weeks.
310 In NCAA division I college football, GPS-derived positional movement characteristics
311 have been quantified (7,28), and biochemical markers of muscle damage associated
312 with pre-season training camp have been examined (8,14). However, research has not
313 attempted to quantify the differences that may exist between practice loads encountered
314 by NCAA division I football players during pre-season training camp with those
315 experienced during the in-season period, and previously this information was limited to
316 coaching intuition and anecdotal reports. It is clear that pre-season training camp is a
317 critical period for football players, yet recommendations have not been established
318 which elucidate effective strategies for periodizing pre-season training camp practices to
319 maximize the position-specific tactical, technical, and physical demands while
320 minimizing the deleterious effects of fatigue. Periodization refers to the logical and
321 systematic process of sequencing and integrating training interventions to achieve peak
322 performance at the appropriate times (13). An ideology that highlights the influence of a
323 properly periodized period of training is referred to as the stimulus-fatigue-recovery-
324 adaptation theory, which suggests that the greater the overall magnitude of the physical
325 demands, the more fatigue accumulates, and the longer the recovery and adaptation
326 process takes (13). When comparing in-season to pre-season practice demands, it is

327 reasonable to suggest that the fatigue associated with pre-season training camp
328 practices in the present study may require increased time recover from, and adapt to,
329 the imposed demands.

330

331 In the present study, an in-season week of training consisted of 3 practices and 1 game,
332 while pre-season1 was comprised of 8 practice sessions in the first 7 days, and as
333 such, the cumulative training load resulting from pre-season1 is increased compared to
334 a typical in-season week of training. This however, does not explain the significantly
335 ($p < 0.05$) greater PLMean and PLMax reported for individual practice sessions of pre-
336 season1, which was likely the result of not only the composition, but the duration of the
337 practice sessions. A greater portion of practice time in pre-season1 was devoted to
338 position-specific skills and techniques than on situational and tactical planning in an
339 offensive or defensive group setting, which commonly occurs throughout in-season
340 practice sessions when preparing for competition. Individual skill work takes place in
341 smaller groups, and allows for increased frequency of movement, potentially resulting in
342 higher PL. The mean session duration in pre-season1 was 145 minutes, however the
343 first practice session of pre-season1 was 169 minutes in duration, which represented
344 the longest practice session of the entire season. The significant increases in PLMax
345 and PLMean that occurred during pre-season1 may therefore be also attributed to
346 practice session duration. Previous research (26) in Australian football has
347 demonstrated that reductions in session duration accompany similar reductions in PL.
348 Specifically, a 30% reduction in duration resulted in a ~30% reduction in PL, and as
349 such, periodizing practice duration may be an effective strategy to reduce PL and

350 facilitate between-session recovery to reduce injury risk and optimize subsequent
351 practice session performance.

352

353 The PLMax and PLMean values reported in pre-season2 were not significantly different
354 than pre-season3, however a significant ($p<0.05$) decrease in both PL measures was
355 demonstrated compared to pre-season1. Week 2 of pre-season consisted of 8 practice
356 sessions with an average practice session duration of 123 minutes. Practice sessions
357 in pre-season2 were programmed to provide less time dedicated to individual position-
358 specific skill work and a larger amount of time to periods of situational drills involving the
359 entire offensive and defensive teams. During the in-season period, the Tuesday
360 practice sessions were planned as the highest practice loads of the week, and PL
361 resulting from in-season Tuesday practices were significantly ($p<0.05$) greater than
362 PLMean in pre-season2 for weeks 2 – 8 during the in-season period. The PL
363 associated with the Tuesday practice session for in-season week 1 was significantly
364 ($p<0.05$) lower than the PLMean in pre-season2, the likely result of a reduction in
365 session duration in attempt to mitigate any deleterious effects of fatigue accumulated in
366 pre-season training camp. A similar pattern was demonstrated for Wednesday practice
367 sessions whereby in-season week 1, 10, 11, and 12 demonstrated significantly ($p<0.05$)
368 lower PL than the PLMean reported in pre-season2. These findings illustrate that
369 coaches may intuitively reduce practice loads during in-season, particularly in the latter
370 part, to maintain the physical capacities developed throughout the pre-season and early
371 in-season periods, but to also provide adequate recovery to support optimal gameday
372 performance.

373

374 A comparison of PLMean from pre-season³ practice sessions with PL resulting from in-
375 season Tuesday and Wednesday practice sessions reveals a decrease in training loads
376 for weeks 9-12 of the season. This appears to be the result of a pre-planned reduction
377 in session duration for Tuesday and Wednesday practices the last four weeks of the
378 season. Similar reductions in PL associated with Thursday practice sessions for the
379 last 4 weeks of the season were not demonstrated, most likely due to the consistent
380 nature of load programming for Thursday practice sessions.

381

382 An examination of the cumulative weekly PL revealed significantly ($p<0.05$) greater
383 cumulative PL for pre-season¹ than pre-season² and ³, and significantly ($p<0.05$)
384 greater cumulative PL for pre-season² than pre-season³. Additionally, all pre-season
385 weeks were associated with significantly ($p<0.05$) greater cumulative PL than all in-
386 season weeks. The significantly ($p<0.05$) increased cumulative workloads
387 demonstrated in pre-season training camp most likely resulted from the increased
388 number of practices when compared to a typical in-season week. However, along with
389 the increased session frequency associated with pre-season training camp, the
390 workloads, particularly in pre-season¹, were also significantly ($p<0.05$) greater than
391 Tuesday, Wednesday, and Thursday in-season practice sessions. Additionally, only
392 one game demonstrated a significantly ($p<0.05$) higher PL than the PLMax achieved in
393 pre-season¹. While the PLMax achieved in pre-season¹ is comparable to the PL which
394 may be experienced by NCAA division I football players during competition, it is
395 reasonable to question the appropriateness of this particular loading scheme for week 1

396 of pre-season training camp, particularly in light of previous research demonstrating
397 increased risk of injury and illness associated with acute spikes in training load
398 indicative of pre-season training camp (16,25).

399

400 American football is associated with high levels of physicality, and as such, practice
401 sessions require adequate intensity to prepare for competitive demands. To improve
402 the likelihood for success, coaches regularly plan practice sessions which challenge the
403 barriers of what players can achieve without exceeding individual training tolerance
404 capacity (25). The present study demonstrated significantly ($p < 0.05$) higher workloads
405 in pre-season¹ than any other phase of pre-season camp, and although the optimal pre-
406 season practice session training load required to produce favorable physical
407 adaptations and mitigate undesirable consequences associated with excessive fatigue
408 has not been established, improvements in load programming may prove
409 advantageous. Research in similar collision-based team sport (16) has demonstrated
410 unfavorable outcomes associated with acute increases in training loads commonly seen
411 in the first week of pre-season practice in NCAA division I football players. An
412 examination (16) of the ratio of acute workload, represented as total distance
413 accumulated over 7 days, compared to chronic workloads, calculated as the 4-week
414 rolling average acute workload, was found to be predictive of injury in rugby league.
415 Specifically, when players were subjected to an acute 7-day workload that was
416 classified as ~ twofold greater than the workload in which they were accustomed to, up
417 to a 10-fold increase in injury occurred. Piggott et. al (25) demonstrated acute spikes in
418 weekly training load (>10%) accounted for ~40% of illness and injury in the subsequent

419 7-day period in Australian footballers. Colby et. al. (4) reported 3-weekly workloads to
420 have the strongest relationship with intrinsic injury incidence in the pre-season and in-
421 season period. Large week-to-week changes in training load also increased the risk of
422 injury in professional rugby players (6). However, increased participation in pre-season
423 practices may reduce the likelihood of injury during the in-season period, presumably by
424 allowing players to accumulate high chronic workloads (16), and perhaps by identifying
425 players who are able to handle higher pre-season training loads and therefore are more
426 robust to injury (30). Performance coaches must have a clear understanding of the
427 planned practice loads associated with pre-season training camp, particularly within the
428 first week, and tailor the preceding weekly conditioning loads leading up to training
429 camp, accordingly. A collaborative approach to pre-season training camp should be
430 implemented, whereby the coaching staff, performance staff, and the medical staff work
431 jointly to develop appropriate loading protocols prior to, and during pre-season training
432 camp, which serve to improve the sport-specific physical capacities but avoid the abrupt
433 increases in PL which have been associated with injury and illness.

434

435 The results of the present study provide novel insight into the contrasting physical
436 demands of NCAA division I football players between the pre-season, particularly in pre-
437 season1, and in-season periods. The findings of the study may seem intuitive to those
438 intimately involved in NCAA division I football, however this is the first investigation to
439 elucidate these suspicions objectively. Despite the novel findings, these data represent
440 one team competing in NCAA division I college football, and consequently, the findings
441 may be limited to this specific team and the philosophy of this particular coaching staff.

442

443 **PRACTICAL APPLICATIONS**

444 The results confirm our hypothesis that significant differences in training loads
445 associated with pre-season training camp, when compared to the in-season competitive
446 period in NCAA division I football players, exist. The most notable findings were the
447 significantly ($p<0.05$) greater PLMax values attributed to pre-season1 compared to PL
448 resulting from all in-season practices, and the significantly ($p<0.05$) higher cumulative
449 PL reported for pre-season1, 2, and 3 compared to every in-season week. Data from
450 the present study augment our understanding of the practice demands experienced by
451 NCAA division I college football players, and provide scope for the improvement of pre-
452 season practice design and physical conditioning strategies for coaches seeking to
453 optimize performance.

454

455 The commencement of the competitive season in college football is highly anticipated
456 by players and coaches alike, and as such, may result in excessive programming of
457 practice volumes and intensities, particularly in pre-season1. An examination (11) in
458 rugby league demonstrated that reductions in pre-season training load, via decreases in
459 session duration, resulted in decreased rates of injury, without negatively impacting
460 improvements in physical fitness. Similar investigations in NCAA football have not been
461 undertaken, however a more deliberate increase in training load, resulting from
462 calculated increases in session duration may be warranted. Purposeful planning of pre-
463 season training camp practices requires collaboration between the sport coaches,
464 performance staff, and medical staff. Limiting the practice session duration, particularly

465 for the initial practices, and throughout first week of pre-season, may prove to be
466 worthwhile.

467

468 For many NCAA football teams, the first week of pre-season camp represents an acute,
469 and often times, significant increase in training load. Coaches seeking to maximize
470 performance and minimize the negative effects of fatigue should make efforts to lessen
471 these acute increases by tightly controlling factors contributing to increases in training
472 load in pre-season¹, and by ensuring athletes are accustomed to these loads prior to
473 the start of pre-season camp. This may be accomplished by limiting the duration of the
474 first pre-season training camp practice, followed by gradual increases in session
475 duration throughout pre-season¹. Additionally, performance coaches should program
476 physical conditioning loads in the weeks leading up to pre-season training camp, that
477 approximate the physical movement demands of pre-season practice sessions.
478 Collectively, these measures may assist in ensuring that the first week of pre-season
479 training camp represents a $\leq 10\%$ increase in training load, and may reduce the
480 likelihood of maladaptation associated with excessive fatigue and under-recovery.

481

482 Future studies should examine how coaches seeking to enhance performance, can
483 manipulate pre-season practice loads, at the team, position, and individual level, to
484 mitigate fatigue, enhance recovery, and optimize game-day performance.

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489

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494

495 **REFERENCES**

496

- 497 1. Boyd, LJ, Ball, K, and Aughey, RJ. Quantifying external load in Australian football
498 matches and training using accelerometers. *Int J Sports Physiol Perform* 8: 44-51,
499 2013.
- 500 2. Boyd, LJ, Ball, K, and Aughey, RJ. The reliability of minimaxx accelerometers for
501 measuring physical activity in Australian football. *Int J Sports Physiol Perform* 6:
502 311-321, 2011.
- 503 3. Chandler, PT, Pinder, SJ, Curran, JD, and Gabbett, TJ. Physical demands of
504 training and competition in collegiate netball players. *J Strength Cond Res* 28:
505 2732-2737, 2014.
- 506 4. Colby, MJ, Dawson, B, Heasman, J, Rogalski, B, and Gabbett, TJ. Accelerometer
507 and gps-derived running loads and injury risk in Australian footballers. *J Strength*
508 *Cond Res* 28: 2244-2252, 2014.
- 509 5. Coutts, AJ, and Duffield, R. Validity and reliability of GPS devices for measuring
510 movement demands of team sports. *J Sci Med Sport* 13: 133-135, 2010.

- 511 6. Cross, MJ, Williams, S, Trewartha, G, Kemp, SP, and Stokes, KA. The influence of
512 in-season training loads on injury risk in professional rugby union. *Int J Sports*
513 *Physiol Perform* 11: 350-355.
- 514 7. DeMartini, JK, Martschinske, JL, Casa, DJ, Lopez, RM, Ganio, MS, Walz, SM, and
515 Coris, EE. Physical demands of National Collegiate Athletic Association division I
516 football players during preseason training in the heat. *J Strength Cond Res* 25:
517 2935-2943, 2011.
- 518 8. Ehlers, GG, Ball, TE, and Liston, L. Creatine kinase levels are elevated during 2-a-
519 day practices in collegiate football players. *J Athl Train* 37: 151-156, 2002.
- 520 9. Gabbett, TJ, Jenkins, DG, and Abernathy, B. Physical collisions and injury during
521 professional rugby league skills training. *J Sci Med Sport* 13: 578-583, 2010.
- 522 10. Gabbett, TJ, Jenkins, DG, and Abernathy, B. Physical demands of professional
523 rugby league training and competition using microtechnology. *J Sci Med Sport* 15:
524 80-86, 2012.
- 525 11. Gabbett, TJ. Reductions in pre-season training loads reduce training injury rates in
526 rugby league players. *Br J Sports Med* 38: 743-749, 2004.
- 527 12. Gallo, T, Cormack, S, Gabbett, T, Williams, M, and Lorenzen, C. Characteristics
528 impacting on session rating of perceived exertion training load in Australian
529 footballers. *J Sports Sci* 33: 467-475, 2015.
- 530 13. Haff, G and Triplett, T (Eds) (2016). *Essentials of strength training and conditioning*,
531 fourth edition. Champaign, IL: Human Kinetics.

- 532 14. Hoffman, JR, Kang, J, Ratamess, NA, and Faigenbaum, AD. Biochemical and
533 hormonal responses during an intercollegiate football season. *Med Sci Sports*
534 *Exerc* 37: 1237-1241.
- 535 15. Hulin, BT, Gabbett, TJ, Johnston, RD, and Jenkins, DG. Wearable microtechnology
536 can accurately identify collision events during professional rugby league match-
537 play. *J Sci Med Sport* 20: 638-642, 2017.
- 538 16. Hulin, BT, Gabbett, TJ, Lawson, DW, Caputi, P, and Sampson, JA. The
539 acute:chronic workload ratio predicts injury: high chronic workload may decrease
540 injury risk in elite rugby league players. *Br J Sports Med* 50: 231-236, 2016.
- 541 17. Johnston, RD, Gabbett, TJ, and Jenkins, DG. Applied sports science of Rugby
542 League. *Sports Med* 44: 1087-1100, 2014.
- 543 18. Johnston, RD, Watsford, ML, Kelly, SJ, Pine, MJ, and Spurrs, RW. Validity and
544 interunit reliability of 10 hz and 15 hz units for assessing athlete movement
545 demands. *J Strength Cond Res* 28: 1649-1655, 2014.
- 546 19. Krasnoff, JB, Kohn, MA, Choy, FKK, Doyle, J, Johansen, K, and Painter, PL.
547 Interunit and intraunit reliability of the RT3 triaxial accelerometer. *J Phys Act Health*
548 5: 527-538, 2008.
- 549 20. McLellan, CP, Lovell, DI, and Gass, GC. Biochemical and endocrine responses to
550 impact and collision during elite Rugby League match play. *J Strength Cond Res*
551 25: 1553-1562, 2011.
- 552 21. McLellan, CP, Lovell, DI, and Gass, GC. Performance analysis of elite rugby league
553 match play using global positioning systems. *J Strength Cond Res* 25: 1703-1710,
554 2011.

- 555 22. Montgomery, PG, Pyne, DB, and Minahan, CL. The physical and physiological
556 demands of basketball training and competition. *Int J Sports Physiol Perform* 5: 75-
557 86, 2010.
- 558 23. Moreira, A, Bilsborough, JC, Sullivan, Cj, Ciancosi, M, Aoki, MS, and Coutts, AJ.
559 Training periodization of professional Australian football players during an entire
560 Australian Football League Season. *Int J Sports Physiol Perform* 10: 566-571,
561 2015.
- 562 24. NCAA Division I manual. *Bylaw 17.10*: p. 252, 2015-2016.
- 563 25. Piggot, B, Newton, MJ, and McGuigan, MR. The relationship between training load
564 and injury and illness over a pre-season at an Australian football league club. *J of*
565 *Aust Strength Cond* 17: 4-17, 2009.
- 566 26. Ritchie, D, Hopkins, WG, Buchheit, M, Cordy, J, and Bartlett, JD. Quantification of
567 training and competition load across a season in an elite Australian football club. *Int*
568 *J Sports Physiol Perform* 11: 474-479, 2016.
- 569 27. Sterczala, AJ, Flanagan, SD, Looney, DP, Hooper, DR, Szivak, TK, Comstock, BA,
570 White, MT, Dupont. WH, Martin, GJ, Volek, JS, Maresh, CM, and Kraemer, WK.
571 Similar hormonal stress tissue damage in response to national collegiate athletic
572 association (NCAA) division I football games played in consecutive seasons. *J*
573 *Strength Cond Res* 28: 3234-3238, 2014.
- 574 28. Wellman, AW, Coad, SC, Goulet, GC, and McLellan, CP. Quantification of
575 competitive game demands of NCAA division I college football players using global
576 positioning systems. *J Strength Cond Res* 30: 11-19, 2016.

- 577 29. Wellman, AW, Coad, SC, Goulet, GC, and McLellan, CP. Quantification of
578 accelerometer derived impacts associated with competitive games in NCAA division
579 I college football players. *J Strength Cond Res* 31: 330-338, 2017.
- 580 30. Windt, J, Gabbett, TJ, Ferris, D, and Khan, KM. Training load-injury paradox: is
581 greater preseason participation associated with lower in-season injury risk in elite
582 rugby league players? *Br J Sports Med* 51: 645-650, 2017.

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Table 1. PLMax Predicted Means. ¹Significantly different than Pre-1, ²Significantly different than Pre-2, ³Significantly different than Pre-3.
Line 2: Lower and Upper limits of 95% Confidence Interval

Seasonal Week	Tuesday	Wednesday	Thursday	Game
Pre-Season1	579.9 (554.5, 605.3)	578.8 (554.3, 603.2)	581.3 (555.5, 607.1)	564.3 (539.1, 589.6)
Pre-Season2	460.8 ¹ (440.4, 481.2)	461.0 ¹ (442.2, 479.7)	464.7 ¹ (442.5, 486.8)	446.7 ¹ (425.8, 467.5)
Pre-Season3	442.9 ¹ (427.6, 458.1)	441.7 ¹ (426.2, 457.2)	444.2 ¹ (423.7, 464.6)	427.2 ¹ (404.7, 449.8)
In-Season 1	353.3 ¹²³ (336.2, 370.4)	322.0 ¹²³ (306.3, 337.7)	285.5 ¹²³ (274.2, 296.8)	538.1 ²³ (493.8, 582.4)
In-Season 2	406.9 ¹²³ (392.4, 421.3)	420.4 ¹²³ (405.1, 435.8)	328.2 ¹²³ (312.0, 344.3)	567.2 ²³ (543.8, 590.7)
In-Season 3	415.8 ¹²³ (397.6, 433.9)	395.6 ¹²³ (380.0, 411.2)	270.0 ¹²³ (245.1, 294.9)	605.7 ¹²³ (584.0, 627.5)
In-Season 4	451.3 ¹ (436.1, 466.5)	408.9 ¹²³ (393.4, 424.4)	307.0 ¹²³ (293.2, 320.7)	525.5 ¹²³ (498.4, 552.7)
In-Season 5	477.3 ¹³ (456.5, 498.2)	425.6 ¹² (407.8, 443.5)	325.4 ¹²³ (309.0, 341.7)	527.4 ¹²³ (508.2, 546.6)
In-Season 6	437.7 ¹ (420.0, 455.5)	408.9 ¹²³ (393.8, 423.9)	298.6 ¹²³ (286.6, 310.5)	514.5 ¹²³ (483.2, 545.8)
In-Season 7	467.1 ¹ (440.7, 493.6)	410.8 ¹²³ (388.5, 433.1)	308.7 ¹²³ (293.2, 324.1)	599.3 ²³ (567.4, 631.3)
In-Season 8	424.8 ¹² (410.7, 438.9)	412.5 ¹²³ (397.5, 427.5)	325.6 ¹²³ (313.0, 338.3)	447.3 ¹ (432.5, 462.0)
In-Season 9	394.7 ¹²³ (380.8, 408.7)	391.9 ¹²³ (379.3, 404.6)	266.5 ¹²³ (254.2, 278.8)	557.2 ²³ (539.2, 575.2)
In-Season 10	401.3 ¹²³ (381.1, 421.5)	353.9 ¹²³ (331.8, 376.0)	315.9 ¹²³ (295.3, 336.4)	488.3 ¹³ (455.6, 520.9)
In-Season 11	381.0 ¹²³ (352.4, 409.6)	347.6 ¹²³ (326.4, 368.7)	332.5 ¹²³ (301.5, 363.5)	530.8 ²³ (508.9, 552.7)
In-Season 12	386.0 ¹²³ (370.1, 401.9)	357.8 ¹²³ (344.7, 371.0)	317.6 ¹²³ (302.0, 333.1)	549.0 ²³ (529.7, 568.2)
# of Observations	422	422	423	*252
*Includes only observations in which there was full participation in Tuesday, Wednesday, and Thursday practice sessions and ≥ 75% game participation.				

Table 2. PLMean and Cumulative PL Predicted Means. ¹Significantly different than Pre-1, ²Significantly different than Pre-2, ³Significantly different than Pre-3.
Line 2: Lower and Upper limits of 95% Confidence Interval

Seasonal Week	Tuesday	Wednesday	Thursday	Game	Cumulative Weekly Player Load
Pre-Season1	466.8 (449.7, 484.0)	465.7 (450.6, 480.8)	468.2 (450.6, 485.8)	453.2 (437.1, 469.4)	3757.5 (3611.5, 3903.4)
Pre-Season2	385.7 ¹ (366.9, 404.5)	385.9 ¹ (368.9, 403.0)	389.6 ¹ (371.2, 408.0)	373.5 ¹ (354.9, 392.0)	3563.9 ¹ (3423.4, 3704.3)
Pre-Season3	377.1 ¹ (363.4, 390.8)	375.9 ¹ (363.8, 388.1)	378.4 ¹ (363.4, 393.4)	363.5 ¹ (342.0, 384.9)	1937.7 ¹² (1861.8, 2013.6)
In-Season 1	353.8 ¹²³ (337.2, 370.4)	322.5 ¹²³ (307.3, 337.7)	286.0 ¹²³ (275.8, 296.1)	537.6 ¹²³ (493.9, 581.4)	1412.9 ¹²³ (1352.9, 1473.0)
In-Season 2	406.8 ¹²³ (392.6, 420.9)	420.3 ¹²³ (404.9, 435.6)	328.0 ¹²³ (311.4, 344.6)	566.5 ¹²³ (541.2, 591.8)	1572.8 ¹²³ (1514.5, 1631.2)
In-Season 3	415.7 ¹²³ (397.2, 434.4)	395.6 ¹ (379.8, 411.5)	270.0 ¹²³ (245.1, 294.9)	606.5 ¹²³ (583.7, 629.3)	1518.2 ¹²³ (1451.3, 1585.1)
In-Season 4	451.7 ²³ (436.2, 467.2)	409.3 ¹²³ (393.9, 424.7)	307.4 ¹²³ (293.9, 320.8)	524.4 ¹²³ (498.0, 550.8)	1642.0 ¹²³ (1576.5, 1707.4)
In-Season 5	477.7 ²³ (456.8, 498.6)	426.0 ¹²³ (407.9, 444.1)	325.8 ¹²³ (309.4, 342.2)	526.5 ¹²³ (508.0, 545.1)	1626.1 ¹²³ (1570.4, 1681.8)
In-Season 6	437.8 ¹²³ (420.0, 455.6)	409.0 ¹³ (393.6, 424.4)	298.7 ¹²³ (286.8, 310.5)	515.7 ¹²³ (483.8, 547.5)	1522.1 ¹²³ (1477.1, 1567.1)
In-Season 7	467.2 ²³ (440.4, 493.9)	410.8 ¹³ (388.4, 433.2)	308.7 ¹²³ (293.1, 324.3)	599.6 ¹²³ (567.4, 631.8)	1645.2 ¹²³ (1581.1, 1709.3)
In-Season 8	424.9 ¹²³ (410.4, 439.3)	412.5 ¹²³ (397.7, 427.4)	325.7 ¹²³ (313.2, 338.2)	446.7 ²³ (433.4, 459.9)	1532.3 ¹²³ (1489.4, 1575.3)
In-Season 9	394.8 ¹ (381.2, 408.3)	392.0 ¹ (379.4, 404.6)	266.5 ¹²³ (254.6, 278.4)	555.7 ¹²³ (537.1, 574.3)	1467.0 ¹²³ (1430.0, 1503.9)
In-Season 10	401.0 ¹ (380.9, 421.1)	353.7 ¹² (332.1, 375.2)	315.6 ¹²³ (295.9, 335.3)	486.6 ²³ (454.7, 518.5)	1435.8 ¹²³ (1377.0, 1494.6)
In-Season 11	381.1 ¹ (352.5, 409.7)	347.6 ¹² (325.9, 369.3)	332.6 ¹²³ (301.7, 363.5)	528.2 ¹²³ (507.2, 549.1)	1446.0 ¹²³ (1362.8, 1529.1)
In-Season 12	385.6 ¹ (369.7, 401.6)	357.5 ¹² (344.6, 370.4)	317.2 ¹²³ (302.0, 332.4)	547.2 ¹²³ (526.4, 568.1)	1472.5 ¹²³ (1410.9, 1534.0)
# of Observations	422	422	423	*252	415
*Includes only observations in which there was full participation in Tuesday, Wednesday, and Thursday practice sessions and ≥ 75% game participation.					

Table 3. Session Duration

Seasonal Week	# of Sessions	Average Duration	Maximum Duration
Pre-Season1	8	2:25:42	2:49:05
Pre-Season2	8	2:03:20	2:20:00
Pre-Season3	6	1:55:00	2:05:00
In-season Tuesday	12	1:58:19	2:05:00
In-Season Wednesday	12	1:52:49	2:04:33
In-Season Thursday	12	1:32:06	1:36:00
Game	12	3:19:17	3:40:00

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