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1 **MOVEMENT DEMANDS AND PERCEIVED WELLNESS**
2 **ASSOCIATED WITH PRE-SEASON TRAINING CAMP IN NCAA**
3 **DIVISION I COLLEGE FOOTBALL PLAYERS**

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9
10 **ABSTRACT**

11
12 The aims of the present study were to examine the movement demands of pre-season
13 practice in National Collegiate Athletic Association (NCAA) division I college football
14 players using portable global positioning system (GPS) technology and to assess
15 perceived wellness associated with pre-season practice to determine if GPS-derived
16 variables from the preceding day influence perceived wellness the following day.

17 Twenty-nine players were monitored using GPS receivers (Catapult Innovations,
18 Melbourne, Australia) during 20 pre-season practices. Individual observations (n=550)
19 were divided into offensive and defensive position groups. Movement variables
20 including low-, medium-, high-intensity, and sprint distance, player load, and
21 acceleration and deceleration distance were assessed. Perceived wellness ratings

22 (n=469) were examined using a questionnaire which assessed fatigue, soreness, sleep
23 quality, sleep quantity, stress, and mood. A one-way ANOVA for positional movement
24 demands, and multi-level regressions for wellness measures were used, followed by
25 post-hoc testing to evaluate the relational significance between categorical outcomes of
26 perceived wellness scores and movement variables. Results demonstrated significantly
27 ($p<0.05$) greater total, high-intensity, and sprint distance, along with greater acceleration
28 and deceleration distances for the DB and WR position groups compared to their
29 respective offensive and defensive counterparts. Significant ($p<0.05$) differences in
30 movement variables were demonstrated for individuals who responded more or less
31 favorably on each of the six factors of perceived wellness. Data from the present study
32 provide novel quantification of the position-specific physical demands and perceived
33 wellness associated with college football pre-season practice. Results support the use
34 of position-specific training and individual monitoring of college football players.

35

36 Key Words: GPS, Monitoring, Questionnaire, American football

37

38 **INTRODUCTION**

39

40 American college football is a physically demanding, full-contact team sport in which
41 players are required to participate in competition necessitating high levels of muscular
42 strength, power, speed and agility, and repeated high-intensity movements (40). In
43 addition to the intense movement demands associated with American football, athletes

44 are exposed to frequent collisions and blunt force trauma associated with repeated
45 contact with opponents and the ground during tackling, blocking, and ball-carrying
46 activities (43). Recent studies (16,39,48) have added to our knowledge of player
47 movement characteristics during National Collegiate Athletic Association (NCAA)
48 division I football competition providing an increased understanding of the positional
49 movement profiles, including the quantification of sprint distances and high-intensity
50 accelerations and decelerations, in addition to a basic understanding of exercise to rest
51 ratios. An additional investigation (49) of NCAA division I college football has revealed
52 the frequency and intensity of impacts and rapid changes of direction, and provided a
53 quantification of the position-specific number and intensity of impacts per game. The
54 movement patterns of NCAA division I football players during competition using global
55 positioning systems (GPS) technology have been reported (48), however limited data
56 (8) exist describing the movement profiles experienced by players during pre-season
57 training camp, that are synonymous with college football competition.

58

59 The development of GPS technology with integrated triaxial accelerometers (IA) have
60 provided a means of quantifying the physical demands of training and competition in
61 contact team sports (1,11,33,48). Improvements in GPS technology have resulted in
62 improved accuracy (17), and have provided a valid and reliable means of assessing
63 activity profiles in team sports (6,19,20,47). Additionally, IA have demonstrated
64 reliability (3) as a means of measuring physical activity across multiple players in team
65 sports, and strong inter-unit relationships ($r=0.996-0.999$) have been demonstrated
66 during high-intensity contact team sport activity.

67

68 College football teams that are similar to other collision-based team sports (5,23),
69 participate in an intensified pre-season training camp that typically commences 4-5
70 weeks prior to the first competition and is associated with a maximum of 29 practice
71 sessions (34). National Collegiate Athletic Association rules govern practice guidelines,
72 permitting teams to designate up to four days for multiple practices, provided the
73 practices do not exceed 5 total hours combined, and they do not occur on consecutive
74 days (34). Programming training loads during the pre-season practice period which
75 maximize positive physiological adaptations, and minimize excessive fatigue that may
76 be associated with maladaptation, can be challenging for coaches and performance
77 staff. While the programming of individual training load prescriptions presents a
78 difficulty in team sports, the prudent monitoring of the individual response to these loads
79 is fundamental for maximizing positive training adaptations (2).

80

81 Monitoring training load involves not only objectively quantifying the volume, intensity,
82 and duration of physical activity completed, commonly referred to as external load, but
83 also the internal load, or the relative physiological and psychological stress imposed as
84 a result of training (13). Previous research in contact team sport, with competitive
85 demands indicative of NCAA division I football, has examined potential measures of an
86 athlete's internal response, including perceived wellness, and the biochemical, and
87 neuromuscular response to training and competition (30,46), however ambiguity exists
88 as to the methods that may be most pertinent to quantify this response (13).

89

90 Subjective measures of mood state and well-being are efficient, inexpensive, and non-
91 invasive (28), have demonstrated sensitivity to training stress, exhibiting a dose-
92 response relationship with training load (38,42), and have been established to be as
93 effective as objective measures in identifying training stress (22). In elite contact team
94 sport, significant correlations have been reported between fluctuations in daily training
95 load and changes in subjective ratings of wellness (4). During intensified periods of
96 competition in sports characteristic of American football, significant changes in
97 perceived well-being accompany performance decrements, decreases in
98 neuromuscular power, and increases in biochemical markers of muscle damage (18).

99

100 There exist a small number of subjective questionnaires that have demonstrated
101 accuracy in assessing athletes' response to training and competition loads including the
102 Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (21), Athlete Burnout
103 Questionnaire (ABQ) (37), and Daily Analysis of Life Demands for Athletes (DALDA)
104 (41) among others. Due to the comprehensive and time-consuming nature of the
105 subjective questionnaires commonly used to monitor athletes' internal training
106 response, the practicality of their implementation presents considerable logistical
107 challenges in a high-performance applied setting (45). A survey of the current trends in
108 fatigue monitoring among Australian and New Zealand high-performance sport revealed
109 that 84% of respondents used self-report questionnaires, 80% of which were custom
110 designed forms consisting of 4-12 items (44). Consequently, it has been recommended

111 that coaches and performance staff utilize brief, customized questionnaires, similar to
112 the one employed by McLean et. al (33) within an athlete monitoring system (15).

113

114 Despite recent advances in our understanding of movement characteristics associated
115 with competition, GPS-derived movement characteristics of multiple position groups
116 resulting from pre-season training camp practices in NCAA division I football players
117 remain unknown. Additionally, the effects of pre-season training camp practice loads
118 that are commonly undertaken in division I college football on the subjective perceptions
119 of wellness are unclear. A more comprehensive understanding of the physiological
120 demands and the resulting subjective psychological response associated with pre-
121 season training camp practice will augment our understanding of the demands of NCAA
122 football players, providing performance coaches a platform to develop training programs
123 that replicate the physical demands of training camp, and allow for the individualization
124 of practice training loads and recovery strategies to enhance performance throughout
125 the pre-season period. The aim of the present study was (a) to examine the positional
126 movement demands associated with pre-season training camp practices in NCAA
127 division I college football players using portable GPS and IA technology and (b) to
128 assess daily perceived wellness associated with pre-season training camp utilizing a
129 custom-designed questionnaire to determine if GPS-derived measures from the
130 preceding day influence perceived ratings of wellness on the following day. We
131 hypothesized that there will be substantial positional differences in the movement
132 demands of NCAA division I football players during pre-season training camp practice,

133 in addition to substantial differences in perceived wellness scores based on the
134 movement demands resulting from practice on the previous day.

135

136 **METHODS**

137

138 **EXPERIMENTAL APPROACH TO THE PROBLEM**

139

140 To examine the positional movement characteristics during NCAA division I football pre-
141 season training camp, portable GPS and IA data were collected from players during 20
142 pre-season practices completed over the course of 20 days. Each individual GPS and
143 IA dataset was divided into specific positional groups for the offense that included wide
144 receivers (WR, 91 observations), quarterbacks (QB, 19 observations), running backs
145 (RB, 40 observations), tight ends (TE, 53 observations), offensive linemen (OL, 80
146 observations), and for the defense that included defensive backs (DB, 100
147 observations), linebackers (LB, 80 observations), defensive ends (DE, 40 observations)
148 and defensive tackles (DT, 47 observations). To determine positional movement
149 profiles, each practice completed was assessed as a single observation.

150

151 To assess perceived wellness associated with pre-season training camp practices, a
152 custom designed form (30) was completed by participants every morning prior to any
153 physical activity. A total of 469 observations were included in present examination which

154 included 78 WR observations, 16 QB observations, 34 RB observations, 46 TE
155 observations, 68 OL observations, 85 DB observations, 68 LB observations, 34 DE
156 observations, and 40 DT observations. For the purposes of examining perceived
157 wellness associated with pre-season camp, only practice data where a survey was
158 completed on the following day, were included in the analysis. For days where two
159 practices occurred, and a survey was taken the following day, both practices were
160 aggregated. Two practices occurred on three separate days, namely days 6, 8, and 13
161 of pre-season training camp. The first two practices of pre-season training camp were
162 completed in helmets only, and therefore were omitted from the analysis.

163

164 **SUBJECTS**

165

166 Twenty-nine National Collegiate Athletic Association (NCAA) Division I Football Bowl
167 Subdivision (FBS) football players (age 20.6 ± 1.1 years; age range 18.3 – 22.8; height
168 187.9 ± 6.5 cm; and mass 108.9 ± 19.8 kg) participated in the present study. Positional
169 anthropometric data are presented in Table 1. All subjects were collegiate athletes
170 whom had been selected to participate in the football program prior to the
171 commencement of the study. All participants in the present study completed the teams'
172 summer off-season physical development training program that included a full-body
173 strength and power training program and specific skills and conditioning sessions
174 designed to simulate the demands of NCAA division I college football practice. The
175 present study comprises the statistical analysis of data collected as part of the day to

176 day student athlete monitoring and testing procedures within the university's football
177 program. Ethical approval was obtained from the university's Institutional Review Board
178 and all subjects signed an institutionally approved informed consent document prior to
179 participating in the study.

180

181 **PROCEDURES**

182

183 *Global Positioning System Units.* Positional movement data were collected in 20
184 practice sessions using a commercially available GPS unit which sampled at 10 Hz
185 (MinimaxX S5; Catapult Innovations, Melbourne, Australia). The unit included a triaxial
186 accelerometer (IA) which operated at 100 Hz and assessed the frequency and
187 magnitude of full-body acceleration ($\text{m}\cdot\text{second}^{-2}$) in three dimensions, namely, anterior-
188 posterior, mediolateral, and vertical (24,32). Prior to the commencement of each
189 practice, GPS receivers were placed outside for 15 minutes to acquire a satellite signal,
190 after which, receivers were placed in a custom designed pocket attached to the
191 shoulder pads of the subjects. Shoulder pads were custom-fit for each individual,
192 thereby minimizing movement of the pads during practices. The GPS and IA receivers
193 used in the present study were positioned in the center of the upper back, slightly
194 superior to the scapulae. Subjects were outfitted with the same GPS receiver for each
195 of the 20 practices. Following the completion of practices, GPS receivers were
196 removed from the shoulder pads, and subsequently downloaded to a computer for
197 analysis utilizing commercially available software (Catapult Sprint 5.1, Catapult

198 Innovations, Melbourne, Australia). Combined tri-axial accelerometer data were
199 presented as PlayerLoad™ (PL), which is a modified vector magnitude expressed as
200 the square root of the sum of the squared instantaneous rates of change in acceleration
201 in each of the three planes and divided by 100 (3). Boyd and colleagues (3) have
202 demonstrated the intra-unit (0.91-1.05 % coefficient of variation [CV]) and inter-unit
203 (1.02-1.10 % CV) reliability of PL and determined its inter-unit reliability in Australian
204 Rules Football matches (1.90% CV). Data provided from GPS receivers were assessed
205 as movement profiles variables including total, low-intensity, medium-intensity, high-
206 intensity, and sprint running distances (m), acceleration and deceleration distances (m),
207 and PL (arbitrary units). Classifications of parameters of movement profile variables are
208 described below and presented in Table 2. Each of the GPS and IA variables
209 measured in the present study was calculated using commercially available software
210 (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia).

211

212 *Movement Classification System.* Movement profile classifications have been described
213 for game analysis in American football (48) and similar contact team sports (31,33).
214 The classification profile utilized in the present study was selected by the researchers to
215 more accurately reflect the demands of American football (48). Each movement
216 classification was coded as one of four speeds of locomotion (Table 2). Low-intensity
217 movements, such as standing, walking and jogging, were considered to be 0 – 12.9
218 km·h⁻¹, medium-intensity movements, such as striding and running, were considered to
219 be 13.0 – 19.3 km·h⁻¹, high-intensity movements, such as fast running for some
220 positional groups, and sprinting for others, were classified as 19.4 – 25.8 km·h⁻¹, and

221 sprinting movements were classified as exceeding $25.8 \text{ km}\cdot\text{h}^{-1}$. Short duration high-
222 intensity movements, or measures of acceleration and deceleration, were classified as
223 four groups, specifically low-intensity ($0 - 1.0 \text{ m}\cdot\text{s}^{-2}$), medium-intensity ($1.1 - 2.0 \text{ m}\cdot\text{s}^{-2}$),
224 high-intensity ($2.1 - 3.0 \text{ m}\cdot\text{s}^{-2}$), and maximal-intensity ($> 3.0 \text{ m}\cdot\text{s}^{-2}$).

225

226 *Wellness Questionnaire.* During pre-season training camp, athletes completed a daily
227 wellness questionnaire based on prior recommendations by Hooper and Mackinnon
228 (15) and previous research in Rugby League, both during intensified periods of training
229 and following competition (18,30,46). This approach to athlete monitoring is consistent
230 with survey data outlining the fatigue-monitoring practices utilized within high-
231 performance sport in Australia and New Zealand (44). The questionnaire utilized in the
232 present study assessed six factors of perceived wellness including fatigue, soreness,
233 sleep quality, sleep quantity, stress, and mood on a 1-5 Likert scale in one-point
234 increments, with higher scores representing more favorable responses (Figure 1). The
235 questionnaire was completed via pen and paper every day before breakfast between
236 7:00 am and 9:00 am, prior to any physical activity, and subsequently downloaded to a
237 laptop for analysis. Similar scales have been shown to have good reliability and validity
238 (7).

239

240 **STATISTICAL ANALYSES**

241

242 The movement metrics selected for categorization in this study, along with all subjective
243 ratings, were used to perform multiple statistical models to capture the statistical
244 analyses necessary for the two main aims of this paper. All models were assessed
245 using the movement metrics as the outcome variable.

246

247 *Positional Movement Demands.* Descriptive statistics were presented as mean \pm
248 standard deviation (SD) for each practice throughout training camp, and Pearson's
249 Correlation was completed to determine the magnitude and direction of covariance
250 across all movement metrics used in this study. Following calculation of descriptive
251 statistics, a one-way ANOVA was conducted for each movement metric to determine if
252 the positions within the offensive and defensive teams had significant differences in
253 each metric. To account for the unbalanced nature of this data, a post-hoc Tukey-
254 Kramer test was used to establish significance across offensive and defensive
255 positions. Statistically significant ($p < 0.05$) differences within the offensive and defensive
256 teams are listed in table 3 and 4.

257

258 *Perceived Wellness.* A series of random effects multi-level regressions, set at the
259 individual and day level, were used to determine the differential effect of specific
260 movement metrics from the previous day on perceived wellness ratings the following
261 day. Categorical outcomes were used to determine less favorable responses (1-2),
262 neutral responses (3), and more favorable responses (4-5) to account for the possibility
263 of non-linear relationships with varying outcomes. Setting the data at the individual and

264 day level allowed for the use of a multi-level model, which mitigates the nested structure
265 of the data within a single day. Following the completion of the regressions, post-hoc
266 testing including t-tests and Wald tests were used to determine relational significance
267 between different categorical outcomes. Significance in all tests was measured at three
268 levels; $p < 0.05$, $p < 0.01$, and $p < 0.001$. The statistical means \pm SD, regression
269 coefficients, and 95% confidence intervals are presented in tables 5-7, and controlled
270 for positional variation. All statistical analyses were performed using Stata
271 Statistical/Data Analysis Software (Stata 14 for Windows, version 14.1; StataCorp,
272 College Station, TX, USA).

273

274 **RESULTS**

275

276 **Positional Movement Demands**

277

278 *Defense:* The characteristics of movement patterns for defensive position groups are
279 outlined in Table 3. Significant ($p < 0.05$) differences were reported for several
280 movement variables measured in the present study for defensive position groups. The
281 DB position group accrued significantly ($p < 0.05$) greater PL, total distance, low-intensity,
282 high-intensity, and sprint running distance than all other defensive position groups. The
283 LB position group demonstrated significantly ($p < 0.05$) greater PL, total, low-intensity,
284 medium-intensity, and high-intensity distance than both the DE and DT position groups.
285 The DB position group accrued significantly ($p < 0.05$) more acceleration and

286 deceleration distance, in all zones of intensity, than all other defensive position groups.
 287 The LB position group demonstrated significantly ($p < 0.05$) greater acceleration and
 288 deceleration distance, in all zones of intensity, than the DT and DE groups, except for
 289 max-intensity acceleration distance, when compared to DE.

290

291 ***Insert Table 3 Here***

292

293 *Offense:* The characteristics of movement patterns for offensive position groups are
 294 outlined in Table 4. Significant ($p < 0.05$) differences were reported for several
 295 movement variables measured in the present study for offensive position groups. The
 296 WR position group demonstrated significantly ($p < 0.05$) greater total, medium-intensity,
 297 high-intensity, and sprint distance than all other offensive position groups, and
 298 significantly ($p < 0.05$) higher PL than all offensive groups, except for the QB.
 299 Additionally, the WR group achieved significantly ($p < 0.05$) greater low-, medium, and
 300 high-intensity acceleration and deceleration distance than all other offensive position
 301 groups, while the RB group demonstrated significantly ($P < 0.05$) higher high-intensity
 302 and max-intensity deceleration distance than the QB, TE, and OL groups. The OL
 303 position group accrued significantly ($p < 0.05$) less total and high-intensity distance, and
 304 significantly ($p < 0.05$) less acceleration and deceleration distance, at all intensities, than
 305 every other offensive position group.

306

307 ***Insert Table 4 Here***

308

309 **Perceived Wellness**

310

311 *Perceived Fatigue:* Significant ($p<0.001$) differences in PL and total distance resulting
312 from practice on the preceding day, were demonstrated in players who rated their level
313 of fatigue a 1 or 2, compared to those who selected 3, 4, or 5. Significant differences in
314 PL ($p<0.001$) and total distance ($p<0.001$) were also demonstrated in those who rated
315 fatigue a 3 compared to those who rated fatigue a 4 or 5. Individuals who rated their
316 perceived fatigue a 1 or 2 covered significantly ($p<0.01$) more acceleration and
317 deceleration distance at all intensities than those who rated their fatigue as a 3.
318 Similarly, significantly ($p<0.01$) more acceleration and deceleration distance at all
319 intensities was accrued during the preceding practice day by those who rated their
320 perceived fatigue a 3 when compared to those who rated it a 4 or 5 (Table 5).

321

322 *Perceived Soreness:* Significant ($p<0.001$) differences in total distance resulting from
323 practice on the preceding day were demonstrated in players who rated their level of
324 soreness a 1 or 2, compared to those who selected 3, 4, or 5, along with significant
325 ($p<0.05$) differences in PL in those who rated perceived soreness a 1 or 2, vs. 3, vs. a 4
326 or 5. Significantly ($p<0.05$) more acceleration and deceleration distance was reported
327 for all intensities for those who rated perceived soreness a 1 or 2 when compared to
328 those who rated it a 3, 4, or 5. Additionally, significantly ($p<0.05$) less maximal-
329 acceleration distance was covered by those who rated their level of soreness a 4 or 5

330 compared to those who rated it a 1 or 2, or a 3. Significantly ($p < 0.001$) less low-,
331 medium-, and high-intensity running distance was covered in those who rated perceived
332 soreness a 3, 4, or 5 compared to individuals who rated perceived soreness a 1 or 2
333 (Table 5).

334

335 *Perceived Sleep Quantity:* Total distance was significantly ($p < 0.05$) lower for those who
336 rated their sleep quantity a 4 or 5 when compared to those who rated sleep quantity a 1,
337 2, or 3. Players loads were significantly ($p < 0.05$) higher for individuals whose perceived
338 sleep quantity was a 1 or 2 compared to 3, and those whose sleep quantity was a 3
339 compared to a 4 or 5. Significantly ($p < 0.05$) greater high-intensity acceleration and
340 deceleration distance, and max-intensity acceleration distance was reported for those
341 who rated sleep quantity a 1 or 2 compared to those who rated it a 3, and for those who
342 rated sleep quantity and 3 compared those whose ratings were a 4 or 5. Significantly
343 ($p < 0.05$) more max-intensity deceleration distance was demonstrated for those who
344 rated sleep quantity a 1 or 2 compared to those rating it a 3, 4, or 5. No significant
345 ($p < 0.05$) differences in GPS and IA variables related to perceived sleep quality existed
346 (Table 6).

347

348 *Perceived Stress and Mood:* No GPS and IA derived variables demonstrated significant
349 differences when examining those who rated their stress level a 1 or 2 compared to
350 those who rated perceived stress a 3. However, individuals who rated stress a 4 or 5
351 had significantly ($p < 0.01$) lower PL, in addition to significantly ($p < 0.01$) less total

352 distance, low-, medium-, and high-intensity distance than those who rated perceived
353 stress a 3. Significant ($p < 0.05$) differences were reported for all intensities of
354 acceleration and deceleration distance, with individuals who rated perceived stress a 4
355 or 5 covering less distance in all zones of intensity than those rating perceived stress a
356 3, and significantly ($p < 0.05$) less high- and max-intensity deceleration distance in those
357 who rated perceived stress a 4 or 5 compared to those whose ratings were a 1, 2, or 3
358 (Table 7). Individuals who rated mood a 4 or 5 accrued significantly ($p < 0.05$) less PL,
359 total distance and maxi-intensity deceleration distance than those who rated their
360 perceived mood a 1 or 2 (Table 7).

361

362 ***Insert Perceived Wellness Tables 5-7 Here***

363

364 **DISCUSSION**

365

366 The present study examined 1) the positional movement demands associated with pre-
367 season training camp practices in NCAA division I college football players using
368 portable GPS and IA technology and 2) assessed the daily perceived wellness
369 associated with pre-season training camp utilizing a custom-designed questionnaire to
370 determine if GPS-derived measures influence perceived ratings of wellness. The
371 results of the present study confirm our hypothesis that 1) significant ($p < 0.05$)
372 differences exist in positional movement demands during pre-season training camp in
373 NCAA division I college football players, and 2) significant ($p < 0.05$) differences in GPS

374 and IA training loads exist in the preceding day's practice for those athletes who rated
375 their perceived wellness less favorable the following day.

376

377 The present study found significant ($p < 0.05$) differences in total distance traveled
378 between position groups within both offensive and defensive teams during pre-season
379 training camp practice. In addition to differences in total distance covered by the WR,
380 DB, and LB position groups, the present study demonstrated significant ($p < 0.05$)
381 differences in high-intensity and sprint distance covered by WR and DB compared to all
382 other positions on their respective offensive or defensive teams. Similar positional
383 differences in division I college football players participating in pre-season training camp
384 were reported by DeMartini et. al (8). An examination (48) of division I college football
385 players participating in competitive games demonstrated significant differences in
386 moderate- ($10.0 - 16.0 \text{ km}\cdot\text{h}^{-1}$), high-intensity ($16.1 - 23.0 \text{ km}\cdot\text{h}^{-1}$), and sprint distances
387 ($> 23.0 \text{ km}\cdot\text{h}^{-1}$) when comparing WR and DB and LB to their offensive and defensive
388 counterparts, which supports the results of the present study, requiring increased
389 running volumes of these positions as a means of preparing for the volumes and
390 intensities associated with pre-season camp and subsequent competitive performance.
391 The positional differences associated with running volumes and intensities observed in
392 the present study may be attributed to position-specific offensive and defensive
393 requirements during training and competition. The primary responsibility of the OL group
394 is to block defensive players, restricting them from tackling the ball carrier. Quick bursts
395 of acceleration, deceleration, and changes of direction, frequently occurring at or near
396 the line of scrimmage, are associated with this tactical responsibility and limit the

397 distance traveled and the velocity achieved during each play. Similarly, players in the
398 DT and DE position groups accelerate short distances and perform rapid change of
399 direction movements prior to, and immediately following, physical contact with the
400 opposing OL. Unlike their offensive and defensive counterparts who are required to
401 travel greater distances prior to engaging an opponent, the OL, DT, and DE positions
402 commence play approximately one meter away from their opponent, thereby limiting
403 subsequent running distances. The differences in high-intensity distance demonstrated
404 by the RB group compared to the OL, QB and TE groups in the present study, may be
405 attributed to the diverse tactical requirements associated with the positional demands of
406 the RB group, including carrying the ball, running pass routes, and blocking to provide
407 protection for the QB on passing plays. The unique physical requirements of the LB
408 position, including engaging OL and TE prior to tackling the ball carrier on running
409 plays, similar to the DT and DE groups, and defending the RB, TE, and WR on passing
410 plays, similar to DB group, are associated with specific movement profile characteristics
411 of this position. The WR position group is required to repeatedly run routes on passing
412 plays, serving as a primary or secondary target, and often on running plays, serving as
413 a decoy to the opposing DB. These position-specific requirements provide explanation
414 for the increased total, high-intensity, and sprint distance associated with the WR
415 position. The DB position is primarily responsible for defending the WR on passing
416 routes, in addition to providing secondary support on running plays, often requiring high-
417 speed pursuit of the ball carrier. Consequently, the DB position is involved in repeated
418 bouts of running, which is reflected in the present study with more total and high-
419 intensity distance than all other defensive position groups.

420

421 An examination of the positional acceleration and deceleration distances revealed
422 significant ($p<0.05$) differences at nearly every intensity, for the DB and LB group
423 compared to other defensive positions. The results of the present study are consistent
424 with the work of Wellman et. al. (48) who reported a significantly ($p<0.05$) greater
425 number of maximal acceleration and deceleration and high-intensity acceleration efforts
426 for the DB position group than all other defensive position groups, and significantly more
427 for the LB group when compared to the DT and DE position group. The results of the
428 present study, along with previous investigations (48) in NCAA division I football,
429 highlight distinct positional movement characteristics within the defensive team.

430 Offensively, the WR position group accumulated significantly ($p<0.05$) greater low-,
431 medium- and high-intensity acceleration and deceleration distance than all other
432 offensive groups. The results of the present study are supported by previous research
433 (48) examining positional movement demands in NCAA division I football players which
434 reported significant ($p<0.05$) differences in acceleration and deceleration efforts for the
435 WR group compared to other offensive position groups. Collectively, these results
436 highlight the importance of developing and implementing a well-planned training
437 program in the weeks preceding the start of training camp, that adequately prepares
438 athletes for the unique positional movement demands associated with pre-season
439 practices. Currently, there is an absence of studies that have investigated the
440 performance demands of NCAA division I football, and the movement demands
441 associated with pre-season training camps are unknown. Accordingly, the present
442 study provides a novel examination of performance related research in NCAA division I

443 football that may be used by coaching and performance staff to develop position-
444 specific training programs to optimize athlete preparation and facilitate on-field
445 performance.

446

447 The present study provides a unique investigation of the perceived wellness associated
448 with pre-season training camp in NCAA division I football players. Significant ($p < 0.01$)
449 differences were reported for every GPS and IA practice variables, except sprint
450 distance, from the preceding day, distinguishing a perceived fatigue rating of 1 or 2 from
451 a 3, and 3 from a 4 or 5. These data indicate the movement characteristics of players
452 on a day to day basis during training camp reflect individual perceptions of fatigue, and
453 support the integration of perceived wellness measures to manage athlete load
454 management during training to avoid decrements in performance and compromised
455 player development. Results of the present study are consistent with previous work (4)
456 using a similar questionnaire in Australian rules football, which reported an increased
457 training load on the preceding day being associated with lower wellness scores the
458 following day during pre-season training camp. A six-week intensified training period in
459 Rugby League players resulted in significant ($p < 0.05$) increases in perceived fatigue
460 with simultaneous significant ($p < 0.05$) decreases in sprint and agility performance, that
461 was followed by significant ($p < 0.05$) improvements in both perceived fatigue and
462 performance measures following a two-week period of reduced training (10).
463 Examinations (30,46) of perceived fatigue following Rugby League competition reported
464 significantly ($p < 0.05$) less favorable fatigue scores accompanied by significant ($p < 0.05$)
465 reductions in neuromuscular performance, with perceptions of fatigue and soreness

466 outlasting reductions in performance measures. In Australian footballers, Gallo et. al
467 (12), reported that pre-training ratings of perceived wellness significantly impacted PL
468 during the subsequent practice session. Although the present study did not examine
469 the impact of perceived fatigue on subsequent practice variables, unfavorable ratings of
470 perceived fatigue may potentially alter exercise tolerance, thereby reducing the quality
471 of practice on the same day. The results of the present study confirm those of previous
472 investigations (4,30,46) highlighting the importance of quantifying and managing the
473 external training load in addition to the perceived fatigue of NCAA division I football
474 players, particularly during and immediately following pre-season training camp.
475 Employing subjective wellness questionnaires similar to the one utilized in the present
476 study, appears to be an effective means of monitoring the internal response to pre-
477 season training camp practices in college football players. Members of the performance
478 staff should work in a collaborative manner with the goal of increasing the physical
479 fitness, supporting the improvement of tactical and technical requirements, and
480 mitigating the risk of undesirable outcomes which may include increased injury risk
481 associated with increased feelings of fatigue (26), illness, and poor performance during
482 pre-season training camp in NCAA division I football players.

483

484 Significant ($p < 0.001$) differences in total, low-, medium-, and high-intensity running and
485 acceleration and deceleration distance at all intensities were demonstrated between
486 individuals who rated their level of perceived soreness a 1 or 2 and those who rated it a
487 3, 4, or 5. Significant ($p < 0.05$) differences in PL distinguished soreness ratings of 1 or 2
488 from a 3, and a 3 from a 4 or 5. Examinations in Australian footballers (4) have also

489 demonstrated daily variations in external load associated with pre-season training camp
490 have a significant ($p < 0.001$) impact on wellness measures, including soreness, fatigue,
491 sleep quality, stress levels and mood the following day. The present study examined
492 the effect of practice loads on perceived wellness the following day, however, muscle
493 soreness may persist for longer periods following fast velocity eccentric muscle
494 contractions that are characteristic of participation in contact team sports like college
495 football (35). Although biochemical markers of soreness were beyond the scope of this
496 study, significant ($p < 0.05$) elevations in creatine kinase have been demonstrated in
497 division I college football players following 4 and 7 days of pre-season training camp (9),
498 likely resulting from the blunt force trauma and eccentric muscle actions associated with
499 collisions and stretch shortening cycle exercise inherent to participation in contact team
500 sports (32). Soreness following intense team sport exercise may be expected,
501 however, clear guidelines do not exist as to what alterations, if any, in training load
502 should be made in response to differing levels of soreness (25). Collectively, the
503 performance team should examine the practice loads of athletes who report persistent
504 soreness to determine if the soreness is an intended consequence of properly
505 programmed loads or an unexpected result of excessive loading, and take appropriate
506 measures, including the modification of subsequent training sessions to reduce the
507 likelihood of cumulative fatigue and performance decrements.

508

509 No significant ($p < 0.05$) differences in GPS and IA variables were reported relating to
510 perceived sleep quality, however significantly ($p < 0.05$) less running distance and
511 acceleration and deceleration distance at all intensities were demonstrated for

512 individuals rating perceived sleep quantity a 4 of 5 vs. a 1, 2, or 3. Additionally,
513 significant ($p<0.05$) differences in GPS variables, including PL, high-intensity
514 acceleration and deceleration distance, and max-intensity acceleration distance were
515 able to distinguish a rating of a 1 or 2 from a 3 and a 3 from a 4 or 5. The findings of the
516 present study are consistent with those of Hauswirth et. al. (14) who reported
517 reductions in sleep quantity associated with overreached athletes participating in
518 intense training. In German Football League players, less favorable ratings of
519 perceived sleep were associated with a significantly ($p=0.01$) higher subsequent risk of
520 injury, indicating that a lack of sleep, or non-refreshing sleep increases injury risk (26).
521 It is reasonable to suggest the reductions in sleep quantity observed in the present
522 study may be attributed to the increased practice loads and the fatigue or muscle
523 soreness associated with those loads (14). Libert et. al. (27) reported decreases in
524 sleep quantity associated with exposure to heat before and during sleep, and as such, it
525 is plausible to suggest that other factors including ambient environmental temperature,
526 which were not controlled for in the present study, may potentially impact sleep. The
527 results of the present study emphasize the importance of individualized athlete
528 monitoring strategies, including perceived measures of sleep quantity, by those seeking
529 to maximize on-field performance and mitigate the deleterious effects of fatigue
530 associated with intense training.

531

532 Individuals who responded more favorably, indicated by a rating of a 4 or 5 for the
533 subscale of perceived stress, demonstrated significantly ($p<0.05$) less PL, total, low-,
534 medium-, and high-intensity running distance and acceleration and deceleration

535 distance at all intensities, in the preceding practice session than those who rated
536 perceived stress a 3. However, significant ($p < 0.05$) differences were not established
537 between those who rated stress a 4 or 5 compared to those who rated stress a 1 or 2
538 for many movement variables, which may be explained by the limited classification of
539 unfavorable ratings for this particular subscale, thus skewing responses toward the
540 normal or more favorable direction. Previous work (4) in Australian footballers has
541 reported that an increase in daily training load associated with a pre-season training
542 camp negatively impacted perceived stress the following day. Similarly, Rugby League
543 players demonstrated increased stress and decreased recovery during an intensified
544 training period (5) supporting the utility of monitoring the individual stress response
545 associated with participating in contact team sports. The findings of the present study
546 and previous examinations in contact team sports (4,5) support the utility of monitoring
547 the individual stress response associated with participating. Previous research (42) has
548 indicated the subscale of emotional stress may provide limited utility for monitoring
549 athlete well-being, while non-training stress has been identified as potentially useful in
550 monitoring acute changes in wellness. The present study did not differentiate between
551 the potential sources of stress, but rather identified stress as a global gestalt measure.
552 In division I college football players, both physical and psychological stress have been
553 positively associated with injury occurrence (29,36), and as such, the inclusion of the
554 stress subscale as part of the daily monitoring of athlete wellness may be advantageous
555 in decreasing the likelihood of maladaptation resulting from all sources of stress
556 associated with participation in division I college football.

557

558 The results of the present study provide novel insight into the position-specific
559 movement demands of NCAA division I pre-season training camp and provide sport and
560 performance coaches with quantified information, which may be used to optimally
561 prepare football players for this intense period of physical training. The present study
562 demonstrated sizeable differences in the positional movement demands of division I
563 football players participating in pre-season camp, highlighting the importance of
564 position-specific training programs to adequately address the physical demands
565 associated with this period of training. In addition, the present study is the first to report
566 the perceived wellness in NCAA division I football players following pre-season training
567 camp practices. Substantial differences in volumes and intensities of GPS and IA
568 movement variables were reported in athletes who responded more or less favorably on
569 perceived wellness subscales. The use of wellness questionnaires may provide sport
570 coaches and performance managers an increased understanding of the training
571 response associated with pre-season training camp practice loads, and provide
572 increased certainty when programming and adjusting the individual training load
573 prescription in pre-season training camp. The ease of administration and cost
574 effectiveness associated with monitoring the athlete training response through
575 subjective means allows football teams, at all levels, to implement these strategies
576 throughout the competitive season without the need for a significant time or monetary
577 investment.

578

579 **PRACTICAL APPLICATIONS**

580

581 Data from the present study increase our understanding of the physical movement
582 demands of pre-season training camp in division I college football players, and provide
583 scope for the design of position-specific training strategies for coaches seeking to
584 optimize training for the demands of pre-season practice. A better understanding of the
585 demands of positional movement demands and perceived wellness associated with pre-
586 season training camp in NCAA division I football players is required to improve the
587 analysis of individual performance characteristics and implement a systematic approach
588 to the development of position-specific training programs. The results of the present
589 study indicate considerable positional differences exist with respect to movement
590 demands and perceived wellness scores during pre-season training camp in NCAA
591 division I football players. Performance coaches should administer position-specific
592 training programs during the summer conditioning period that adequately prepare
593 players for the physical demands of pre-season camp. Specifically, an appropriate
594 volume of total, high-intensity, and sprint distance, in addition to acceleration and
595 deceleration distance should be undertaken prior to pre-season training camp.

596

597 The present study also provided a novel analysis of the physiological and psychological
598 response to exercise loads associated with practice on the preceding day. These data
599 support the use of daily perceived measures of wellness to quantify the internal
600 response to practice loads in division I football players participating in pre-season
601 training camp. Subjective measures of perceived wellness, including fatigue, soreness,
602 sleep quantity, and stress appear to be sensitive to differences in training load from the
603 preceding practice day in NCAA division I football players, and may be used to monitor

604 the adaptive response to pre-season training camp practices. It is up to coaches and
605 performance staff to determine if unfavorable wellness scores are an intended
606 consequence of participation in pre-season practices or an unintended result of
607 improper practice volumes and intensities. Minimizing the deleterious effects of fatigue
608 while simultaneously improving the position-specific technical, tactical, and physical
609 demands associated with athlete preparation in division I college football players
610 requires a collaborative effort between members of the coaching staff, medical staff,
611 performance staff, and most importantly, the athletes themselves. The ease of
612 administration, cost-effectiveness, and the minimal time investment required to collect
613 perceived wellness data, makes it a practical tool for monitoring team sport athletes.

614

615 Data obtained from the present study provide a better understanding of the movement
616 demands and the resultant physiological and psychological responses of NCAA division
617 I football players to pre-season training camp. This information provides a foundation
618 from which to implement a systematic approach to the development of individual and
619 position-specific training programs that adequately prepare athletes for the rigors of this
620 period of time. Future investigations should examine the impact of perceived wellness
621 scores on performance and injury risk.

622

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624

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629

630 REFERENCES

631

- 632 1. Austin, DJ, and Kelly, SJ. Professional Rugby League positional match-play analysis
633 through the use of global positioning system. *J Strength Cond Res* 28: 187-193,
634 2013.
- 635 2. Borresen, J and Lambert, MI. The quantification of training load, the training
636 response and the effect on performance. *Sports Med* 39: 779-795, 2009.
- 637 3. Boyd, LJ, Ball, K, and Aughey, RJ. The reliability of minimaxx accelerometers for
638 measuring physical activity in Australian football. *Int J Sports Physiol Perform* 6:
639 311-321, 2011.
- 640 4. Buchheit, M, Racinais, S, Bilsborough, JC, Bourdon, PC, Voss, SC, Hocking, J,
641 Cordy J, Mendez-Villanueva, A, and Coutts, AJ. Monitoring fitness, fatigue and
642 running performance during a pre-season training camp in elite football players. *J*
643 *Sci Med Sport* 16: 550-555, 2013
- 644 5. Coutts, AJ and Reaburn, P. Monitoring changes in rugby league players' perceived
645 stress and recovery during intensified training. *Percept mot skills* 106: 904-916,
646 2008.

- 647 6. Coutts, AJ, and Duffield, R. Validity and reliability of GPS devices for measuring
648 movement demands of team sports. *J Sci Med Sport* 13: 133-135, 2010.
- 649 7. De Vries, J, Michielsen, H, and Van Heck, GL. Assessment of fatigue among
650 working people: a comparison of six questionnaires. *Occup Environ Med* 60: i10-i15,
651 2003.
- 652 8. DeMartini, JK, Martschinske, JL, Casa, DJ, Lopez, RM, Ganio, MS, Walz, SM, and
653 Coris, EE. Physical demands of National Collegiate Athletic Association division I
654 football players during preseason training in the heat. *J Strength Cond Res* 25:
655 2935-2943, 2011.
- 656 9. Ehlers, GG, Ball, TE, and Liston, L. Creatine kinase levels are elevated during 2-a-
657 day practices in collegiate football players. *J Athl Train* 37: 151-156, 2002.
- 658 10. Elloumi, M, Makni, E, Moalla, W, Bouaziz, T, Tabka, Z, Lac, G, and Chamari, K.
659 Monitoring training load and fatigue in rugby sevens players. *Asian J Sports Med* 3:
660 175-184, 2012.
- 661 11. Gabbett, TJ, Jenkins, DG, and Abernethy, B. Physical demands of professional
662 rugby league training and competition using microtechnology. *J Sci Med Sport* 15:
663 80-86, 2011.
- 664 12. Gallo, T, Cormack, S, Gabbett, T, and Lorenzen, C. Pre-training perceived wellness
665 impacts training output in Australian football players. *J Sports Sci* 34: 1445-1451,
666 2016.
- 667 13. Halson, SL. Monitoring training load to understand fatigue in athletes. *Sports Med*
668 44: 139-147, 2014.

- 669 14. Hauswirth, C, Louis, J, Aubry, A, Bonnet, G, Duffield, R, and Le Meur, Y. Evidence
 670 of disturbed sleep and increased illness in overreached endurance athletes. *Med Sci*
 671 *Sports Exerc* 46: 1036-1045, 2014.
- 672 15. Hooper, SL, and Mackinnon, LT. Monitoring overtraining in athletes,
 673 recommendations. *Sports Med* 20: 321-327, 1995.
- 674 16. Iosia, MF, and Bishop, PA. Analysis of exercise-to-rest ratios during division I
 675 televised football competition. *J Strength Cond Res* 22: 332-340, 2008.
- 676 17. Johnston, RD, Gabbett, TJ, and Jenkins, DG. Applied sports science of Rugby
 677 League. *Sports Med* 44: 1087-1100, 2014.
- 678 18. Johnston, RD, Gibson, NV, Twist, C, Gabbett, TJ, MacNay, SA, and MacFarlane,
 679 NG. Physiological responses to an intensified period of rugby league competition. *J*
 680 *Strength Cond Res* 27: 643-654, 2013.
- 681 19. Johnston, RD, Watsford, ML, Kelly, SJ, Pine, MJ, and Spurrs, RW. Validity and
 682 interunit reliability of 10 hz and 15 hz units for assessing athlete movement
 683 demands. *J Strength Cond Res* 28: 1649-1655, 2014.
- 684 20. Johnston, RD, Watsford, ML, Pine, MJ, Spurrs, RW, Murphy, AJ, and Pruyn, EC. The
 685 validity and reliability of 5-hz global positioning system units to measure team sport
 686 movement demands. *J Strength Cond Res* 26: 758-765, 2012.
- 687 21. Kellmann, M and Kallus, KW. (2001). *Recovery-stress questionnaire for athletes:*
 688 *User manual*. Champaign, IL: Human Kinetics.
- 689 22. Kellmann, M. Preventing overtraining in athletes in high-intensity sports and
 690 stress/recovery monitoring. *Scand J Med Sci Sports* 20: 95-102, 2010.

- 691 23. Killen, NM, Gabbett, TJ, and Jenkins, DG. Training loads and incidence of injury
 692 during the preseason in professional rugby league players. *J Strength Cond Res* 24:
 693 2079-2084, 2010.
- 694 24. Krasnoff, JB, Kohn, MA, Choy, FKK, Doyle, J, Johansen, K, and Painter, PL.
 695 Interunit and intraunit reliability of the RT3 triaxial accelerometer. *J Phys Act Health*
 696 5: 527-538, 2008.
- 697 25. Lambert, MI, and Borresen, J. A theoretical basis of monitoring fatigue: a practical
 698 approach for coaches. *Int J Sports Sci Coach* 1: 371-388, 2006.
- 699 26. Laux, P, Krumm, B, Driers, M, and Flor, H. Recovery-stress balance and injury risk
 700 in professional football players: a prospective study. *J Sports Sci* 33: 2140-2148,
 701 2015.
- 702 27. Libert, JP, Di Nisi, J, Fukuda, H, Muzet, A, Ehrhart, J, and Amoros, C. Effect of
 703 continuous heat exposure on sleep stages in humans. *Sleep* 11: 195-209, 1988.
- 704 28. Main, L and Grove, JR. A multi-component assessment model for monitoring training
 705 distress among athletes. *Eur J Sport Sci* 9: 195-202, 2009.
- 706 29. Mann, BJ, Bryant, KR, Johnstone, B, Ivey, PA, and Sayers, SP. Effect of physical
 707 and academic stress on illness and injury in division I college football players. *J*
 708 *Strength Cond Res* 30: 20-25, 2016.
- 709 30. McLean, DB, Coutts, AJ, Kelly, V, McGuigan, MR, and Cormack, SJ.
 710 Neuromuscular, endocrine, and perceptual fatigue responses during different length
 711 between-match microcycles in professional rugby league players. *Int J Sports*
 712 *Physiol Perform* 5: 367-383, 2010.

- 713 31. McLellan, CP and Lovell, DI. Performance analysis of professional,
 714 semiprofessional, and junior elite rugby league match-play using global positioning
 715 systems. *J Strength Cond Res* 27: 3266-3274, 2013.
- 716 32. McLellan, CP, Lovell, DI, and Gass, GC. Biochemical and endocrine responses to
 717 impact and collision during elite Rugby League match play. *J Strength Cond Res* 25:
 718 1553-1562, 2011.
- 719 33. McLellan, CP, Lovell, DI, and Gass, GC. Performance analysis of elite rugby league
 720 match play using global positioning systems. *J Strength Cond Res* 25: 1703-1710,
 721 2011.
- 722 34. NCAA Division I manual. *Bylaw 17.10*: p. 252, 2015-2016.
- 723 35. Paddon-Jones, D, Keech, A, Lonergan, A, and Abernethy, P. Differential expression
 724 of muscle damage in humans following acute fast and slow velocity eccentric
 725 exercise. *J Sci Med Sport* 8: 255-263, 2005.
- 726 36. Petrie, TA. The moderating effects of social support and playing status on the life
 727 stress-injury relationship. *J Appl Sport Psychol* 5: 1-16, 1993.
- 728 37. Raedeke, TD and Smith, AL. Development and preliminary validation of an athlete
 729 burnout measure. *J Sport Exerc Psychol* 23: 281-306, 2001.
- 730 38. Raglin, JS. Psychological factors in sport performance: the mental health model
 731 revisited. *Sports Med* 31: 875-890, 2001.
- 732 39. Rhea, MR, Hunter, RL, and Hunter, TJ. Competition modeling of American football:
 733 observational data and implications for high school, collegiate, and professional
 734 player conditioning. *J Strength Cond Res* 20: 58-61, 2006.

- 735 40. Robbins, DW and Young, WB. Positional relationships between various sprint and
 736 jump abilities in elite American football players. *J Strength Cond Res* 26: 338-397,
 737 2012.
- 738 41. Rushall, BS. A tool for measuring stress tolerance in elite athletes. *App Sport*
 739 *Psychol* 2: 51-66, 1990.
- 740 42. Saw, AE, Main, LC, and Gatin, PB. Monitoring the athlete training response:
 741 subjective self-reported measures trump commonly used objective measures: a
 742 systematic review. *Br J Sports Med* 0: 1-13, 2015.
- 743 43. Sterczala, AJ, Flanagan, SD, Looney, DP, Hooper, DR, Szivak, TK, Comstock, BA,
 744 White, MT, Dupont. WH, Martin, GJ, Volek, JS, Maresh, CM, and Kraemer, WK.
 745 Similar hormonal stress tissue damage in response to national collegiate athletic
 746 association (NCAA) division I football games played in consecutive seasons. *J*
 747 *Strength Cond Res* 28: 3234-3238, 2014.
- 748 44. Taylor, KL, Chapman, DW, Cronin, JB, Newton, MJ, and Gill, N. Fatigue monitoring
 749 in high performance sport: a survey of current trends. *J Aust Strength Cond* 20: 12-
 750 23, 2012.
- 751 45. Twist, C and Highton, J. Monitoring fatigue and recovery in rugby league players. *Int*
 752 *J Sports Physiol Perform* 8: 467-474, 2013.
- 753 46. Twist, C, Waldron, M, Highton, J, Burt, D, and Daniels, M. Neuromuscular,
 754 biochemical and perceptual post-match fatigue in professional rugby league
 755 forwards and backs. *J Sports Sci* 30: 359-367, 2012.

- 756 47. Varley, MC, Fairweather, IH, and Aughey, RJ. Validity and reliability of GPS for
757 measuring instantaneous velocity during acceleration, deceleration, and constant
758 motion. *J Sports Sci* 30: 121-127, 2012.
- 759 48. Wellman, AW, Coad, SC, Goulet, GC, and McLellan, CP. Quantification of
760 competitive game demands of NCAA division I college football players using global
761 positioning systems. *J Strength Cond Res* 30: 11-19, 2016.
- 762 49. Wellman, AW, Coad, SC, Goulet, GC, and McLellan, CP. Quantification of
763 accelerometer derived impacts associated with competitive games in NCAA division
764 I college football players. *J Strength Cond Res* 31: 330-338, 2017.