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1 **Title: Movement and Physiological demands of**
2 **Australasian National Rugby League Referees**

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Abstract

Purpose: To evaluate the movement and physiological demands of the Australasian National Rugby League (NRL) referees, officiating with a 'two referee' (i.e., 'lead' and 'pocket') system and to compare the demands of the lead referee and pocket referees.

Methods: 10 Hz global positioning system devices were used to obtain 86 data sets ('lead', $n=41$; 'pocket', $n=45$) on 19 NRL referees. Total distance, relative distance covered and heart rate per half and across match-play was examined within and between referees using t-tests. Distance, time and number of movement 'efforts' were examined in six velocity classifications (i.e., standing <0.5 ; walking $0.51-2.0$; jogging $2.01-4.0$; running $4.01-5.5$; high speed running $5.51-7.0$; sprinting $> 7.0 \text{ m.s}^{-1}$) using ANOVA. Cohen's d effect sizes were reported.

Results: There were no significant differences between the 'lead' and 'pocket' referee for any movement or physiological variable. There was an overall significant (large; very large) effect for distance (% distance) and time (% time) ($P < 0.001$) between each velocity classification for both the 'lead' and 'pocket' referee. Both roles covered the largest distance and number of efforts at velocities between $0.51-2.0 \text{ m.s}^{-1}$ and $2.01-4.0 \text{ m.s}^{-1}$, which were interspersed with efforts $>5.51 \text{ m.s}^{-1}$.

Conclusions: Findings highlight the intermittent nature of rugby league refereeing, but show that there were no differences in the movement and physiological demands of the two refereeing roles. Findings are valuable for those responsible for the preparation, training and conditioning of NRL referees, and to ensure training prepares for and simulates match demands.

Key Words: Match officiating; match demands; intermittent physical demands; heart rate; time-motion analysis.

Introduction

Rugby league (RL) is an intermittent team sport involving bouts of high-intensity physical activity separated by bouts of low speed activity performed over two 40 minute halves.¹ Rugby league referees are an essential part of the game. They are responsible for enforcing the laws of the game, regulating the behaviour of the players, and their decisions can influence the outcome of a game. The European Super League (SL) and Australian National Rugby League (NRL) are the most prominent elite competitions in world rugby league.² Global Positioning System (GPS) analysis has become a popular technology for evaluating the movement and physiological demands of sports and there is a growing literature within the area.²⁻⁴ However there is limited research on the movement and physiological demands of rugby league referees with only two SL^{5,6} and three NRL studies respectively.⁷⁻⁹

A study on NRL referees ('one referee' system) identified that the mean total distance covered during match play was 7607 m⁹ with most distance covered (67%; 4651 m) between 0 – 1.94 m.s⁻¹ (walking/slow jogging), with 6% (443 m) between 4.72 – 8.33 m.s⁻¹ (sprinting). In comparison Kay and Gill⁷ found NRL referees ('one referee' system) to cover 6700 ± 400 m with jogging (56%) making up the largest proportion of distance covered, but with 2% consisting of sprinting (movement was categorised based on gait characteristics, no speed thresholds were provided). Mean distance covered by SL referees during match play has been reported to be 7114 ± 748 m⁶, consisting of 200 ± 149 m (2.8%) at a running speed > 5.51 m.s⁻¹. O'Hara et al⁵ found a total distance covered of 8951 ± 746 m with the greatest distance covered between 2.01 – 4.0 m.s⁻¹ (42%; 3717 m), but with a calculated distance of 5% (515 m) > 5.51 m.s⁻¹. Together, these studies indicate that NRL and SL refereeing consists of bouts of high intensity activity, interspersed with periods of low intensity exercise. The relative distance covered by SL referees has been reported to be 77.9 ± 9.6⁶ and 104.8 ± 10.0 m.min⁻¹.⁵ However, it is not possible to conclude if this large difference is of practical importance as the data was collected using different sampling frequency GPS devices, 10 Hz and 5 Hz respectively. Similar relative heart rates 79 – 84 %HR_{max} during match play^{6,8,9} have also been reported for both NRL and SL referees.

Comparisons between the running demands of NRL and SL referees is problematic given studies utilised GPS devices with different sampling frequencies or time motion analysis methods (i.e., video analysis). Moreover, studies of NRL referees used only 1 Hz GPS devices⁹ and video analysis⁷, which have poorer validity and inter-unit reliability than GPS devices with higher sampling frequencies.^{10,11} Utilising GPS devices with lower

151 sampling frequencies (1 Hz and 5 Hz) could provide an
152 inaccurate estimation of the external load of referees, therefore
153 preventing coaches and conditioning staff from accurately
154 conditioning referees to the demands of match play.¹¹ Therefore,
155 to better understand the movement demands of NRL referees,
156 studies should employ 10 Hz GPS devices.

157

158 Historically, rugby league games have been officiated by a single
159 on-field referee, supported by two touch judges, and more
160 recently a video referee. The referee has to control the 10 m
161 defensive line whilst positioning themselves in the best possible
162 place to make a decision. However, in 2009 the NRL adopted a
163 ‘two referee’ system. Anecdotally, the aim of this policy was to
164 reduce the physical stress of the game on single referees, and to
165 help try and ensure better decision making in the game. Within
166 the NRL, the ‘lead’ referee assumes the more traditional role of
167 holding the 10 m defensive line and controlling play, whilst the
168 assistant referee (‘pocket’ referee) monitors the ‘play-the-ball’,
169 sitting in the space (i.e., ‘pocket’) behind the attacking team’s
170 ruck. The ‘two referee’ system is also associated with
171 experience. Typically more experienced referees adopt the ‘lead’
172 role for approximately 80% of the game, and the ‘pocket’ for
173 20%; whilst the other less experienced referee acts as the
174 ‘pocket’ and ‘lead’ for 80% and 20% respectively. Due to the
175 role of the ‘pocket’, positioned behind the ruck following play,
176 this role was believed to cover a greater distance within a game.
177 However, to date no research directly evaluating the physical and
178 movement demands of Rugby League referees using the ‘two
179 referee’ system has been undertaken to confirm this. This study
180 therefore seeks to be the first and most comprehensive analysis
181 of the movement and physiological demands of the NRL ‘two
182 referee’ system utilising 10Hz global positioning system (GPS)
183 devices.

184

185 The aims of this study were to evaluate the movement and
186 physiological demands of the NRL referees officiating with a
187 ‘two referee’ system using 10Hz GPS devices and to compare
188 the demands of the ‘lead’ and ‘pocket’ referee. It was
189 hypothesised that the ‘pocket’ referee would cover the greater
190 distances during a game when compared to the ‘lead’ referee due
191 to the requirements of following play behind the ruck.

192

193

Materials & Methods

194

Subjects

195 Nineteen NRL referees participated in this study. Eleven referees
196 officiated as the ‘lead’ referee (age 38 ± 3.5 years; stature 177.6
197 ± 6.1 cm; body mass 81.3 ± 8.7 kg) and fourteen as the ‘pocket’
198 referee (age 35 ± 2.9 years; stature 178.0 ± 6.2 cm; body mass
199 79.5 ± 9.5 kg). Therefore, 6 referees acted as both a ‘lead’ and
200 ‘pocket’ referee. All referees were given detailed information on

201 the procedures and gave written informed consent. Institutional
202 ethics approval in the spirit of the Helsinki Declaration, was
203 granted and permission to undertake the research was granted by
204 the National Rugby League (NRL) General Manager of Football
205 Operations.

206

207 *Design*

208 Time-motion analysis was undertaken on a total of 45 NRL
209 domestic matches during the 2013 NRL season using portable
210 10Hz GPS devices (MinimaxX S4; Catapult Sports, Australia:
211 88x50x19 mm in size, 67 g in weight) which include tri-axial
212 accelerometers sampling at 100 Hz. The 10 Hz GPS devices
213 (Catapult Sports, Australia) have been reported to be valid and
214 reliable⁴ and it has been reported that 10 Hz GPS devices are
215 two to three times more accurate than 5 Hz devices.¹² Heart rate
216 monitors (Polar Electro, Kempele, Finland) were also worn by
217 referees in those matches. Data were collected from Round 5 of
218 NRL competition up to and including the Grand Final. Eleven
219 referees officiated as the 'lead' referee, and fourteen as the
220 'pocket' ('lead' only $n = 5$; pocket only $n = 8$; both $n = 6$) across
221 data collection. The referee's previous games experience ranged
222 from 2 ($n = 2$ referees) to 278 games, with 'leads' and 'pockets'
223 typically having refereed on average 133 ± 74 and 58 ± 59 games
224 respectively, by the start of the 2013 season. Data for the entire
225 rugby league match were recorded for 'lead' referees on 41
226 occasions and the 'pocket' for 45 occasions. There was a mean
227 of 3.7 ± 2.4 matches per 'lead' referee and 3.2 ± 2.4 matches per
228 'pocket' referee. Data was collected on the 'lead' and 'pocket'
229 referee for the same match on 39 occasions. Discrepancies in the
230 number of matches reported to those recorded is due to exclusion
231 of GPS data in cases where the 'lead' ($n = 6$) or 'pocket' referee
232 ($n = 2$) did not activate or wear the unit, there was no or poor
233 satellite coverage, or battery failure.

234

235 *Procedures*

236 Referees were fitted with a vest, which housed a GPS device
237 between the scapulae. On match day, prior to warming up,
238 referees activated the GPS device. The heart rate monitor was
239 positioned around the chest underneath the GPS vest, with the
240 referee's shirt worn over the top. Referees were familiar with
241 wearing the GPS devices and heart rate monitors during matches,
242 due to both piloting and briefing information.

243

244 For all matches the number of satellites ranged from 10 to 13
245 (11.2 ± 1.0) with a horizontal dilution of precision of 1.8 ± 0.8 .
246 A low value (within the range 0-50) for the horizontal dilution
247 of precision indicates an optimal geometrical positioning of
248 orbiting satellites for accurate monitoring of position.^{4,13} Total
249 distance (m), relative distance covered ($\text{m} \cdot \text{min}^{-1}$), and percentage
250 of match heart rate maximum ($\% \text{HR}_{\text{max}}$) during match play and

251 per half were examined. Movement was categorised into six
252 velocity classifications according to prior criteria.¹⁴ These were
253 standing ($< 0.5 \text{ m}\cdot\text{s}^{-1}$), walking ($0.51 - 2.0\text{m}\cdot\text{s}^{-1}$), jogging ($2.01 -$
254 $4.0 \text{ m}\cdot\text{s}^{-1}$), running ($4.01 - 5.5 \text{ m}\cdot\text{s}^{-1}$) high speed running ($5.51 -$
255 $7.0 \text{ m}\cdot\text{s}^{-1}$; HSR) and sprinting ($> 7.0 \text{ m}\cdot\text{s}^{-1}$). Such velocity
256 classifications were deemed appropriate as they've been
257 previously applied in time motion analyses of Rugby League
258 referees⁵ and rugby league players.¹⁵ Even though these
259 qualitative descriptors have different relative meaning to the
260 range of velocities that can be achieved by each referee, the
261 selected absolute velocity classifications were deemed
262 appropriate as they allowed comparison with the literature.
263 However as the qualitative descriptive may be potentially
264 confusing, the absolute velocity classifications were used
265 throughout the reporting and discussion of findings. In each
266 velocity classification, total mean distance, percentage distance,
267 time (minutes), percentage time, and the mean number of
268 movement 'efforts' were examined. An 'effort' is when the
269 referee has entered a velocity zone and remains in the zone for
270 at least 1 second. The distance of 'efforts' within the velocity
271 classification was examined using four predefined distances, as
272 classified by the Catapult Sprint software, 0 - 5 m, 5.01 - 10 m,
273 10.01 - 40 m and $> 40 \text{ m}$.

274
275 Heart rate data was not included and examined if heart rate was
276 lost during the match or if there was no corresponding GPS data
277 resulting in 29 'lead' (from $n = 10$ referees) and 30 'pocket'
278 (from $n = 12$ referees) heart rate data sets. A referee's heart rate
279 maximum was the peak heart rate achieved during match play
280 and this value was used to calculate relative heart rate intensities,
281 a method used within the literature.^{6,16} All data was downloaded
282 to a PC and analysed using Catapult Sprint 5.1.2 (Catapult
283 Innovations, Australia) software and once appropriately
284 formatted for data management it was exported to Microsoft
285 Excel (Microsoft Corporation, USA).

286
287 *Statistics*

288 Due to the uneven number of matches per referee to reduce bias,
289 each referee's data mean was used to calculate 'lead' and
290 'pocket' means and were used for statistical analysis.
291 Preliminary assessments checked for violations of normality
292 using Kolomgorov-Smirnov and homogeneity of variances
293 using Levene's test. Then, independent t-tests were used to
294 assess differences between the 'lead' and 'pocket' referee on the
295 movement and physiological variables. A paired samples t-test
296 within each group of referee ('lead' and 'pocket') assessed for
297 differences between the first and second half for physiological
298 and movement demands. A one-way repeated measures analysis
299 of variance (ANOVA) with Bonferroni *post-hoc* procedure
300 assessed for differences between velocity classifications within

301 each group of referees. Data are reported as mean \pm standard
302 deviation. Statistical significance was set at $P < 0.05$ and
303 Cohen's d effect size (ES) was reported using a modification to
304 the effect size scale of Cohen.¹⁷ The magnitude of the effect size
305 was classified as; trivial < 0.2 , small $0.21 - 0.6$, moderate $0.61 -$
306 1.2 , large $1.21 - 1.99$, and very large > 2.0 .¹⁸

307

308

Results

Total and relative distance covered

310 The total distances covered in match play ranged from 5462 to
311 8536 m, and 6770 to 8675 m for the 'lead' and 'pocket' referee
312 respectively. There were no significant differences (trivial and
313 small ES) between the mean distance covered by the 'lead' and
314 'pocket' in the first half, second half, or in total match play
315 (Table 1). The relative distance covered in match play ranged
316 from 62.0 to 89.5 $\text{m}\cdot\text{min}^{-1}$ and 75.7 to 96.7 $\text{m}\cdot\text{min}^{-1}$ for the 'lead'
317 and 'pocket' referee respectively. There were no significant
318 differences (small ES) in the relative distance covered by the
319 'lead' and 'pocket' referee in total match play, or in the first or
320 second half (Table 1).

321

322 No significant differences (trivial and small ES) were found
323 between the mean distance and relative distance covered in the
324 first half when compared to lower distances in the second half
325 (Table 1) for the 'lead' ($P = 0.469$, $d = 0.17$ and $P = 0.080$, $d =$
326 0.47 respectively) and 'pocket' ($P = 0.880$, $d = 0.03$ and $P =$
327 0.053 , $d = 0.48$ respectively) referee.

328

329 The 'pocket' referee covered a significantly (moderate ES)
330 higher distance at $0.51 - 2.0 \text{ m}\cdot\text{s}^{-1}$ in the second half when
331 compared to the first half (Table 2). There were no further
332 significant differences ($P > 0.05$; trivial and small ES) found
333 between the first and second half distance covered at each
334 movement velocity classification for the 'lead' and 'pocket'
335 referee independently. The 'lead' and 'pocket' referee covered
336 less distance at $5.51 - 7.0 \text{ m}\cdot\text{s}^{-1}$ (small and moderate ES
337 respectively) in the second half when compared to the first half.

338

Heart rate responses

340 There were no significant differences between referee roles for
341 $\%HR_{\text{max}}$ in the first half and second half even though the 'pocket'
342 referee had a higher $\%HR_{\text{max}}$ in the first half compared to the
343 'lead' referee (moderate ES). The $\%HR_{\text{max}}$ for total match play
344 was similar for the 'lead' and 'pocket' referee (Table 1). Both
345 referee roles had a significantly (moderate ES) higher $\%HR_{\text{max}}$
346 in the first half when compared to the second half ($P = 0.022$, d
347 $= 0.60$; $P = 0.000$, $d = 0.76$ respectively).

348

349

Insert Table 1 and 2 here

350

351 *Velocity Classifications*

352 Table 3 displays the between ('lead' vs 'pocket') referee results,
353 with Table 4 and 5 displaying the associated within ('lead' and
354 'pocket' independently) results. There were no significant
355 differences ($P > 0.05$; small and trivial ES) between the 'lead'
356 and 'pocket' referee in the mean distance and time at each
357 movement velocity classification (Table 3).

358

359 ****Insert Table 3 and 4 here****

360

361 Table 4 shows an overall significant difference ($P < 0.001$) and
362 large to very large ES for distance covered and % distance
363 between each velocity classification for both the 'lead' and
364 'pocket' referee. Where there were no significant differences
365 there were moderate to large ES. Both referee roles covered the
366 greatest distance (% distance) between 2.01 – 4.0 m.s⁻¹. Table 5
367 shows an overall significant difference ($P < 0.001$) and very
368 large ES for time and % time between each velocity
369 classification for both referee roles. Where there were no
370 significant differences there were large ES. Both referee roles
371 spent the most time (% time) < 2.01 m.s⁻¹.

372

373 ****Insert Table 5 and 6 here****

374

375 There was a significant moderate difference between the 'lead'
376 and 'pocket' in the number of efforts between 10 and 40m at a
377 velocity greater than 7 m.s⁻¹ ($P = 0.044$, $d = 0.82$) (Table 6).
378 There were no other significant differences in the mean
379 frequency of movement efforts in total and by distance in each
380 velocity classification. Both the 'lead' and 'pocket' referee
381 performed the greatest number of efforts between 0.51 – 2.0 m.s⁻¹
382 ¹, with the number of efforts performed decreasing as the
383 velocity increased. However, the number of efforts at velocities
384 > 2.0 m.s⁻¹ increased in distance up to 40 m.

385

386

Discussion

387 This is the first study to evaluate the movement and
388 physiological demands of the NRL 'two referee' officiating
389 system and compare the demands of the respective roles using
390 10 Hz GPS devices. Therefore present findings, when compared
391 to prior studies on NRL referees⁷⁻⁹, can be considered as giving
392 the most comprehensive and accurate analysis of the movement
393 and physiological demands of NRL referees to date and the only
394 research to assess the 'two referee' system, which can be used to
395 inform conditioning programmes for these referees. A key
396 finding of this study was that despite the differing roles of the
397 'lead' and 'pocket' referee, there were no differences in the
398 movement and physiological demands between each role. This
399 observation does not support the study's original hypothesis.
400 There was one exception, with a higher number of efforts > 7

401 m.s⁻¹ between 10 m and 40 m performed by the ‘lead’ referee.
402 However, these efforts equated to less than one effort per game
403 for each referee, and as such has no real world meaning. This
404 study has also re-affirmed the intermittent nature of rugby league
405 refereeing at this elite standard, with the greatest distances and
406 efforts performed at velocities <4.0 m.s⁻¹, interspersed with
407 efforts >5.51 m.s⁻¹.

408
409 Both referee roles covered similar total distance to that
410 previously reported on NRL referees by Hoare (7607 m)⁹ but
411 higher than those reported by Kay and Gill (6700 ± 400 m).⁷
412 Most of the distance covered was between 0.51 – 4.0 m.s⁻¹ which
413 is also similar to data reported for NRL referees.⁹ The highest
414 number of efforts were observed between 0.51 – 2.0 m.s⁻¹ with
415 the distance of efforts increasing as the velocity increased (> 2.0
416 m.s⁻¹). This suggests that slow velocity efforts of short distance
417 are interspersed with longer distance efforts at higher velocities
418 (> 2.0 m.s⁻¹) demonstrating the intermittent nature of NRL
419 referee movement demands. Assessing differences in the
420 findings with other studies who have utilised different movement
421 analysis systems should be done with caution, as prior studies
422 have shown large between-system differences using video-based
423 time-motion analysis systems, as well as 1 Hz and 5 Hz GPS
424 systems.¹⁹ Others have reported that an increase in sampling rate
425 (5 Hz to 10 Hz) improves the validity and inter-unit reliability of
426 GPS units¹⁰, and that when compared to 1 Hz and 5 Hz GPS
427 units, the 10 Hz GPS unit provides an improved measure of
428 movement demands.¹¹

429
430 There was no significant difference (small ES) for either the
431 ‘lead’ or ‘pocket’ referee in relative distance covered between
432 halves. However, both roles had a lower relative distance and
433 covered a lower distance between 5.51 – 7.0 m.s⁻¹ in the 2nd half.
434 NRL players have shown significantly lower relative distance in
435 the 2nd half compared to the 1st half (2nd = 87.4 ± 8.8; 1st = 92.6
436 ± 9.4 m.min⁻¹).² Research has suggested that this decrease in the
437 second half for elite rugby league players could be due to a
438 change in tactics or the onset of fatigue.²⁰ As referees have to
439 keep up with play at all times in order to minimise the possibility
440 of an incorrect decision²¹ the decrease in relative distance from
441 the 1st half to the 2nd half could be explained by a reduction in
442 the players actions or fatigue in referees, which is unclear at this
443 stage. Future research assessing direct comparisons between
444 elite rugby players and referees movement and physiological
445 demands is warranted.

446
447 The mean heart rate values for the NRL ‘lead’ and ‘pocket’
448 referee were consistent with previous research on NRL
449 referees.^{8,9} Findings show that there was a significantly
450 (moderate ES) lower %HR_{max} in the 2nd half in both the ‘lead’

451 and 'pocket'. These findings are consistent with the lower
452 relative distance covered in the 2nd half in both roles. There was
453 no significant difference (small ES) between the NRL 'lead' and
454 'pocket' referee in the second half and in total %HR_{max}, however
455 there was a higher first half %HR_{max} (moderate ES) observed in
456 the 'pocket' referee. Previous research has suggested that an
457 increase in heart rate may be associated with factors other than
458 the physiological demands of refereeing such as anxiety⁸,
459 stress²² and experience²³. In relation to the NRL referees the
460 'pocket' referee is the least experienced of the two referees and
461 therefore further research analysing how experience and other
462 factors may impact the physiological demands is required.

463

464

Practical Applications

465 Current findings allow those responsible for the training and
466 conditioning of NRL referees to better understand the movement
467 and physiological demands of the 'lead' and 'pocket' referee.
468 Such information can enable practitioners to develop and
469 enhance training programmes to ensure they reflect the specific
470 physical match demands. As there were no role specific
471 movement and physiological demand differences, similar
472 training drills and conditioning programmes can be utilised,
473 which may be beneficial when referees have to adopt both roles
474 during a playing season. These findings can also enable aspiring
475 referees to better understand the movement and physiological
476 requirements of elite NRL referees to officiate at the highest
477 level of domestic rugby league. This may include developing
478 highly intermittent training activities including interspersing low
479 intensity efforts with high intensity efforts (> 5.51 m.s⁻¹) of
480 differing distances and intensities. To replicate, the
481 physiological demands of refereeing conditioning programmes
482 should include training which elicits an average heart rate of ≈
483 84 %HR_{max}.

484

485 Although there are currently no rugby league referee training
486 research studies, high intensity intermittent running training has
487 been reported to improve soccer referees fitness levels and
488 therefore match performance.²¹ A referee's weekly training
489 programme should have a blend of high and low intensity
490 aerobic sessions, as well as including sessions to improve
491 running economy, repeat sprint ability and high-intensity
492 intermittent endurance. A typical training week should aim to
493 include 2-3 high intensity intermittent training sessions, which
494 incorporates multi-directional movement to mimic the demands
495 of the game.²⁴ It is important to note that when training referees,
496 during a training week efforts that 'overload' the match demands
497 should be included. This type of training will hopefully enable
498 the rugby referee to keep up with play with reduced effort,
499 allowing them the optimal viewing position, to make a correct
500 decision.

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Conclusions

This is the first study to evaluate the movement and physiological demands of NRL ‘lead’ and ‘pocket’ referees, officiating within the ‘two referee’ system using 10 Hz GPS devices. In comparing these referee roles, based on repeated measures of many referees across multiple rounds of NRL matches, no differences in the total distance, relative distance covered and %HR_{max} during match play were apparent. Likewise, there were no differences between the referee roles in the distance, percentage distance, time, percentage time and number of efforts, within all movement velocity classifications. Findings thus demonstrate the intermittent and similarity of on-field movement demands for NRL referees, regardless of referee role. Refereeing in either role at the professional elite level involves frequent changes of velocity of differing distances, with periods of low velocity efforts interspersed with short high velocity efforts.

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Table 1. Movement and Physiological Demands for the NRL ‘Lead’ and ‘Pocket’ Referee (mean \pm sd and effect sizes).

	Lead Referee			Pocket Referee			Lead v Pocket Referee		
	1 st Half	2 nd Half	Total	1 st Half	2 nd Half	Total	1 st Half	2 nd Half	Total
Total Distance (m)	3746 \pm 385	3681 \pm 439	7427 \pm 775	3811 \pm 280	3799 \pm 315	7610 \pm 523	$P = 0.628$ $d = 0.18$	$P = 0.441$ $d = 0.31$	$P = 0.487$ $d = 0.27$
Relative Distance (m.min⁻¹)	83.7 \pm 7.4	79.8 \pm 9.0	81.8 \pm 7.6	85.6 \pm 7.4	82.2 \pm 6.9	83.9 \pm 6.5	$P = 0.528$ $d = 0.26$	$P = 0.460$ $d = 0.30$	$P = 0.450$ $d = 0.30$
Average Heart Rate (% HR_{max})	84.0 \pm 2.6*	82.3 \pm 3.1	83.0 \pm 2.7	86.1 \pm 3.7†	83.5 \pm 3.2	84.7 \pm 3.4	$P = 0.142$ $d = 0.67$	$P = 0.373$ $d = 0.38$	$P = 0.223$ $d = 0.55$

* indicates a significant difference between 1st and 2nd half for NRL lead referee ($P < 0.05$)

† indicates a significant difference between 1st and 2nd half for NRL pocket referee ($P < 0.001$)

Table 2. Distance at Each Movement Velocity Classification for the NRL ‘Lead’ and ‘Pocket’ Referee Independently (mean \pm sd and effect sizes).

Velocity	Lead Referee			Pocket Referee		
	Total Distance (m)			Total Distance (m)		
	1 st Half	2 nd Half		1 st Half	2 nd Half	
< 0.5 m.s ⁻¹	194 \pm 170	181 \pm 109	$P = 0.545$ $d = 0.09$	180.5 \pm 103.4	209.6 \pm 165.5	$P = 0.310$ $d = 0.21$
0.51-2.0 m.s⁻¹	1312 \pm 80.1	1313 \pm 121	$P = 0.972$ $d = 0.01$	1248 \pm 81.7	1301 \pm 62.4	$P = 0.002$ $d = 0.73$
2.01-4.0 m.s⁻¹	1650 \pm 346	1663 \pm 367	$P = 0.840$ $d = 0.04$	1784 \pm 263	1761 \pm 329	$P = 0.658$ $d = 0.08$
4.01-5.5 m.s⁻¹	481 \pm 168	443 \pm 166	$P = 0.149$ $d = 0.23$	494 \pm 131	451 \pm 163	$P = 0.282$ $d = 0.29$
5.51-7.0 m.s⁻¹	69.5 \pm 41.3	58.7 \pm 36.3	$P = 0.192$ $d = 0.28$	74.6 \pm 46.8	51.3 \pm 28.3	$P = 0.068$ $d = 0.60$
> 7.0 m.s ⁻¹	8.4 \pm 10.7	4.3 \pm 6.3	$P = 0.173$ $d = 0.47$	3.6 \pm 7.3	3.6 \pm 9.4	$P = 0.988$ $d = 0.01$

Grey indicates a significant difference between 1st and 2nd half ($P < 0.05$)

Table 3: Distance and Time at Each Movement Velocity Classification for the NRL ‘Lead’ and ‘Pocket’ Referee (mean ± sd and effect sizes).

Velocity	Lead Referee				Pocket Referee				Lead v Pocket Referee			
	Distance (m)	Distance (%)	Time (minutes)	Time (%)	Distance (m)	Distance (%)	Time (minutes)	Time (%)	Distance (m)	Distance (%)	Time (minutes)	Time (%)
< 0.5 m.s ⁻¹	374 ± 277	5.8 ± 5.6	33.6 ± 4.6	36.8 ± 5.3	390 ± 256	5.7 ± 4.5	33.5 ± 3.5	36.8 ± 3.3	<i>P</i> = 0.883 <i>d</i> = 0.06	<i>P</i> = 0.966 <i>d</i> = 0.02	<i>P</i> = 0.999 <i>d</i> = 0.02	<i>P</i> = 0.990 <i>d</i> = 0.00
0.51-2.0 m.s ⁻¹	2627 ± 168	36.0 ± 4.2	34.1 ± 2.2	37.5 ± 2.6	2548 ± 137	34.1 ± 3.2	33.0 ± 2.1	36.3 ± 1.9	<i>P</i> = 0.213 <i>d</i> = 0.52	<i>P</i> = 0.210 <i>d</i> = 0.52	<i>P</i> = 0.194 <i>d</i> = 0.51	<i>P</i> = 0.173 <i>d</i> = 0.54
2.01-4.0 m.s ⁻¹	3311 ± 680	43.8 ± 6.2	19.0 ± 3.8	21.0 ± 4.0	3545 ± 562	45.8 ± 5.4	20.1 ± 3.0	22.2 ± 3.3	<i>P</i> = 0.356 <i>d</i> = 0.39	<i>P</i> = 0.405 <i>d</i> = 0.35	<i>P</i> = 0.397 <i>d</i> = 0.32	<i>P</i> = 0.387 <i>d</i> = 0.33
4.01-5.5 m.s ⁻¹	922 ± 325	12.0 ± 3.4	3.4 ± 1.2	3.7 ± 1.3	945 ± 258	12.0 ± 2.8	3.5 ± 0.9	3.9 ± 1.2	<i>P</i> = 0.846 <i>d</i> = 0.08	<i>P</i> = 0.991 <i>d</i> = 0.00	<i>P</i> = 0.949 <i>d</i> = 0.10	<i>P</i> = 0.680 <i>d</i> = 0.17
5.51-7.0 m.s ⁻¹	129 ± 72.6	1.7 ± 0.9	0.4 ± 0.2	0.4 ± 0.5	126 ± 63.6	1.6 ± 0.7	0.4 ± 0.2	0.3 ± 0.4	<i>P</i> = 0.912 <i>d</i> = 0.04	<i>P</i> = 0.642 <i>d</i> = 0.19	<i>P</i> = 0.917 <i>d</i> = 0.09	<i>P</i> = 0.543 <i>d</i> = 0.25
> 7.0 m.s ⁻¹	12.7 ± 14.8	0.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	7.2 ± 12.5	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	<i>P</i> = 0.327 <i>d</i> = 0.40	<i>P</i> = 0.989 <i>d</i> = 0.00	<i>P</i> = 0.261 <i>d</i> = 0.52	

Table 4: Difference and Effect Sizes in Distance and % Distance at Each Movement Velocity Classification for the NRL ‘Lead’ and ‘Pocket’ Referee Independently

Velocity	Distance						% Distance					
	< 0.5m.s ⁻¹	0.51-2.0m.s ⁻¹	2.01-4.0m.s ⁻¹	4.01-5.5m.s ⁻¹	5.51-7.0m.s ⁻¹	> 7.0m.s ⁻¹	< 0.5m.s ⁻¹	0.51-2.0m.s ⁻¹	2.01-4.0m.s ⁻¹	4.01-5.5m.s ⁻¹	5.51-7.0m.s ⁻¹	> 7.0m.s ⁻¹
< 0.5m.s ⁻¹		<i>P</i> < 0.001 <i>d</i> = 9.85	<i>P</i> < 0.001 <i>d</i> = 5.66	<i>P</i> = 0.107 <i>d</i> = 1.82	<i>P</i> = 0.369 <i>d</i> = 1.21	<i>P</i> = 0.023 <i>d</i> = 1.84		<i>P</i> < 0.001 <i>d</i> = 6.13	<i>P</i> < 0.001 <i>d</i> = 6.44	<i>P</i> = 0.425 <i>d</i> = 1.34	<i>P</i> = 0.702 <i>d</i> = 1.01	<i>P</i> = 0.109 <i>d</i> = 1.43
0.51-2.0m.s ⁻¹	<i>P</i> < 0.001 <i>d</i> = 10.52		<i>P</i> = 0.086 <i>d</i> = 1.37	<i>P</i> < 0.001 <i>d</i> = 6.60	<i>P</i> < 0.001 <i>d</i> = 19.3	<i>P</i> < 0.001 <i>d</i> = 21.95	<i>P</i> < 0.001 <i>d</i> = 7.29		<i>P</i> = 0.293 <i>d</i> = 1.48	<i>P</i> < 0.001 <i>d</i> = 6.33	<i>P</i> < 0.001 <i>d</i> = 11.37	<i>P</i> < 0.001 <i>d</i> = 12.17
2.01-4.0m.s ⁻¹	<i>P</i> < 0.001 <i>d</i> = 7.24	<i>P</i> < 0.001 <i>d</i> = 2.45		<i>P</i> < 0.001 <i>d</i> = 4.48	<i>P</i> < 0.001 <i>d</i> = 6.58	<i>P</i> < 0.001 <i>d</i> = 6.86	<i>P</i> < 0.001 <i>d</i> = 8.09	<i>p</i> = 0.001 <i>d</i> = 2.66		<i>P</i> < 0.001 <i>d</i> = 6.37	<i>P</i> < 0.001 <i>d</i> = 9.51	<i>P</i> < 0.001 <i>d</i> = 9.97
4.01-5.5m.s ⁻¹	<i>P</i> = 0.009 <i>d</i> = 2.16	<i>P</i> < 0.001 <i>d</i> = 7.77	<i>P</i> < 0.001 <i>d</i> = 5.96		<i>P</i> < 0.001 <i>d</i> = 3.37	<i>P</i> < 0.001 <i>d</i> = 3.95	<i>P</i> = 0.053 <i>d</i> = 1.67	<i>P</i> < 0.000 <i>d</i> = 7.39	<i>P</i> < 0.001 <i>d</i> = 7.89		<i>P</i> < 0.001 <i>d</i> = 4.13	<i>P</i> < 0.001 <i>d</i> = 4.94
5.51-7.0m.s ⁻¹	<i>P</i> = 0.043 <i>d</i> = 1.42	<i>P</i> < 0.001 <i>d</i> = 22.7	<i>P</i> < 0.001 <i>d</i> = 8.56	<i>P</i> < 0.001 <i>d</i> = 4.36		<i>P</i> = 0.003 <i>d</i> = 2.22	<i>P</i> = 0.074 <i>d</i> = 1.28	<i>P</i> < 0.000 <i>d</i> = 14.22	<i>P</i> < 0.001 <i>d</i> = 11.56	<i>P</i> < 0.001 <i>d</i> = 5.07		<i>P</i> = 0.002 <i>d</i> = 2.28
> 7.0m.s ⁻¹	<i>P</i> < 0.001 <i>d</i> = 2.11	<i>P</i> < 0.001 <i>d</i> = 26.14	<i>P</i> < 0.001 <i>d</i> = 8.91	<i>P</i> < 0.001 <i>d</i> = 5.13	<i>P</i> = 0.003 <i>d</i> = 2.59		<i>P</i> = 0.005 <i>d</i> = 1.75	<i>P</i> < 0.001 <i>d</i> = 15.23	<i>P</i> < 0.001 <i>d</i> = 12.05	<i>P</i> < 0.001 <i>d</i> = 5.95	<i>P</i> < 0.001 <i>d</i> = 2.65	

Grey indicates lead referee data / No shading indicates the pocket referee

Bold text indicates a significant difference / *d* = Cohen’s *d* effect size

Table 5: Differences and Effect Sizes in Time and % Time at Each Movement Velocity Classification for the NRL ‘Lead’ and ‘Pocket’ Referee Independently

Velocity	Time						% Time					
	< 0.5m.s ⁻¹	0.51-2.0m.s ⁻¹	2.01-4.0m.s ⁻¹	4.01-5.5m.s ⁻¹	5.51-7.0m.s ⁻¹	> 7.0m.s ⁻¹	< 0.5m.s ⁻¹	0.51-2.0m.s ⁻¹	2.01-4.0m.s ⁻¹	4.01-5.5m.s ⁻¹	5.51-7.0m.s ⁻¹	> 7.0m.s ⁻¹
< 0.5m.s ⁻¹		p = 1.000 d = 0.14	p = 0.002 d = 3.45	P < 0.001 d = 8.98	P < 0.001 d = 10.16	P < 0.001 d = 10.27		P = 1.000 d = 0.17	P = 0.003 d = 3.40	P < 0.001 d = 8.65	P < 0.001 d = 9.76	P < 0.001 d = 9.91
0.51-2.0m.s ⁻¹	P = 1.000 d = 0.17		P < 0.001 d = 4.86	P < 0.001 d = 17.49	P < 0.001 d = 21.60	P < 0.001 d = 21.90	P = 1.000 d = 0.19		P < 0.001 d = 4.96	P < 0.001 d = 16.62	P < 0.001 d = 20.13	P < 0.001 d = 20.72
2.01-4.0m.s ⁻¹	P < 0.001 d = 4.09	P < 0.001 d = 4.95		P < 0.001 d = 5.57	P < 0.001 d = 6.93	P < 0.001 d = 7.06	P < 0.001 d = 4.44	P < 0.001 d = 5.32		P < 0.001 d = 5.88	P < 0.001 d = 7.31	P < 0.001 d = 7.52
4.01-5.5m.s ⁻¹	P < 0.001 d = 11.75	P < 0.001 d = 18.24	P < 0.001 d = 7.44		P < 0.001 d = 3.59	P < 0.001 d = 4.04	P < 0.001 d = 13.16	P < 0.001 d = 20.72	P < 0.001 d = 7.44		P < 0.001 d = 3.31	P < 0.001 d = 3.99
5.51-7.0m.s ⁻¹	P < 0.001 d = 13.38	P < 0.001 d = 21.92	P < 0.001 d = 9.20	P < 0.001 d = 4.71		p = 0.003 d = 2.32	P < 0.001 d = 15.42	P < 0.001 d = 26.86	P < 0.001 d = 9.42	P < 0.001 d = 3.97		P = 0.185 d = 1.30
> 7.0m.s ⁻¹	P < 0.001 d = 13.53	P < 0.001 d = 22.21	P < 0.001 d = 9.37	P < 0.001 d = 5.30	P < 0.001 d = 2.79		P < 0.001 d = 15.68	P < 0.001 d = 27.75	P < 0.001 d = 9.63	P < 0.001 d = 4.57	P = 0.129 d = 1.17	

Grey indicates lead referee data / No shading indicates the pocket referee

Bold text indicates a significant difference / d = Cohen’s d effect size

Table 6: Frequency of Movement Efforts in Total and by Distance in Each Velocity Classification for the NRL ‘Lead’ and ‘Pocket’ Referee (mean ± sd and effect sizes).

Velocity	Lead Referee					Pocket Referee					Lead v Pocket Referee				
	Total	0-5 m	5-10 m	10-40 m	40 m+	Total	0-5 m	5-10 m	10-40 m	40 m+	Total	0-5 m	5-10 m	10-40 m	40 m+
0.51-2.0 m.s ⁻¹	395 ± 17.0	221 ± 21.3	108 ± 11.1	64.9 ± 10.1	1.2 ± 0.7	393 ± 30.5	227 ± 32.5	105 ± 9.5	61.3 ± 8.6	1.4 ± 1.3	P = 0.898 d = 0.08	P = 0.655 d = 0.22	P = 0.465 d = 0.30	P = 0.343 d = 0.39	P = 0.649 d = 0.18
2.01-4.0 m.s ⁻¹	231 ± 36.7	27.5 ± 6.3	74.5 ± 14.3	122 ± 28.7	7.8 ± 4.5	233 ± 26.0	27.0 ± 10.1	70.7 ± 14.7	125 ± 20.2	9.8 ± 4.8	P = 0.927 d = 0.06	P = 0.882 d = 0.06	P = 0.522 d = 0.26	P = 0.729 d = 0.12	P = 0.285 d = 0.44
4.01-5.5 m.s ⁻¹	65.2 ± 22.7	4.27 ± 2.4	19.6 ± 7.2	40.8 ± 14.2	0.5 ± 0.4	66.5 ± 15.3	4.8 ± 1.7	22.1 ± 5.2	38.5 ± 8.9	1.1 ± 1.0	P = 0.863 d = 0.07	P = 0.533 d = 0.25	P = 0.308 d = 0.40	P = 0.627 d = 0.19	P = 0.119 d = 0.69
5.51-7.0 m.s ⁻¹	7.8 ± 5.0	0.0 ± 0.0	2.6 ± 2.5	5.1 ± 2.9	0.1 ± 0.2	7.1 ± 3.4	0.0 ± 0.0	2.1 ± 1.9	4.8 ± 2.3	0.2 ± 0.4	P = 0.686 d = 0.16		P = 0.591 d = 0.22	P = 0.783 d = 0.11	P = 0.506 d = 0.28
> 7.0 m.s ⁻¹	0.6 ± 0.7	0.0 ± 0.0	0.1 ± 0.2	0.6 ± 0.7	0.0 ± 0.0	0.3 ± 0.6	0.0 ± 0.0	0.1 ± 0.3	0.1 ± 0.3	0.1 ± 0.2	P = 0.201 d = 0.53		P = 0.839 d = 0.08	P = 0.044 d = 0.82	P = 0.118 d = 0.64
Total	700 ± 72.1	253 ± 22.6	204 ± 22.9	233 ± 46.1	9.65 ± 4.2	700 ± 56.9	258 ± 39.9	200 ± 21.5	230 ± 30.6	12.6 ± 5.3	P = 0.996 d = 0.00	P = 0.707 d = 0.15	P = 0.600 d = 0.18	P = 0.838 d = 0.08	P = 0.148 d = 0.62

Grey indicates a significant difference between NRL lead and pocket referee (P < 0.05)