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Physical performance and decision making in association football referees: A naturalistic study.

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1 **Method**

2 *Participants*

3   *Match Officials.*   Five New Zealand Football Championship (NZFC) referees, officiating

4 in seven NZFC games agreed to participate in the study. Two referees participated twice in games

5 involving different teams. All held the NZ badge qualification and two were Fédération Internationale

6 de Football Association (FIFA) qualified referees. This represents half of the referees who officiate in

7 this league. They were all male, aged from 31-43 yrs old (mean = 38.2 yrs, $s = 5.89$) and all had

8 refereed in the National League for at least 4 years. New Zealand Soccer provided the estimated

9 maximal oxygen uptake ($\dot{V}O_{2\,max}$) scores achieved by each referee completing a 12-minute run[see

10 36] at the beginning of the season (mean = 55.4 ml.kg^{-1}.min^{-1}, $s = 5.90$). All the referees received a

11 detailed explanation of the purpose of the research and were assured of the confidentiality of their

12 datasets prior to the study commencing.

13 *Referee Panel.*   A separate panel of five experienced referees also participated by providing

14 independent judgments of selected incidents in the games from edited video clips. Participants were

15 recruited from members of the local referees' society, all of whom officiate alongside the subject

16 sample during New Zealand's winter competitions. All held the NZ badge qualification and one was

17 a FIFA qualified referee. The age and experience of these referees (mean age = 38.2 yrs, $sd = 12.6$;

18 mean experience = 9.5 yrs, $sd = 7.1$) also closely matched that of the subject sample. These

19 individuals were sent a copy of the DVD and a set of rating sheets and asked to complete the ratings

20 in their own time. The rating sheet included instructions asking them to watch each clip as many

21 times as they felt necessary in order to be confident in their decision and to indicate the number of

22 viewings required on the sheet. They also indicated whether the clip was of sufficient quality and held

23 enough information to make an informed decision and any additional comments they felt necessary to

24 include about the clip.

25

1   *Procedure*

2   Data were collected at seven home games of Otago United Football Club in the NZ Football

3   Championship (played between November 2005 and February 2006). Each match was recorded by

4   two JVC-2000 DV cameras from elevated positions at the top of the main grandstand and on the

5   opposite side of the pitch. The pitch side camera was manually operated to provide a detailed close-

6   up view of the action, while the grandstand camera, also manually operated, recorded a wide-angle

7   view including both the active play and the position of referee.

8   Each referee was fitted with a HR monitor and a SPI-10 Global Positioning System

9   (GPSports, Fyshwick, Australia) transmitter 45 minutes before the start of each game. The GPS

10   transmitter was worn in a light harness placed over the shoulders and under the referee's shirt. The

11   GPS equipment collects and stores positional data at a sampling frequency of 1 Hz by comparing

12   signals from between 6 and 9 satellites. The equipment also records, by radio telemetry, the HR

13   signals from a strap worn around the referee's chest. The initiation of video and GPS recording was

14   manually synchronised 30 minutes before the kick-off of each game to ensure that all data had the

15   same timeline. The data recording ended as the referee left the pitch at the end of each game.

16

17   *GPS Analysis*

18   The GPS transmitter recorded the referee's position, speed of movement, and HR at 1-

19   second intervals throughout each game. A recent assessment of the validity of this GPS system has

20   found a relatively small systematic overestimation of absolute distance (within 4.8% ± 7.2% [37]).

21   From the raw data, a number of other variables related to physical demand were calculated by the

22   GPS[1] equipment's software (such as frequency and distance of sprints/jogs/walks, and percentage of

23   time spent engaging at different exercise intensities). The following locomotor categories were used;

24   standing and walking 0-7 km.h^{-1}; jogging 7–12 km.h^{-1}; moderate running 12-18 km.h^{-1}; and sprinting

25   above 18 km.h^{-1} (adjusted from speeds used by Drust, Reilly, & Cable[38]). These four categories

1   were subsequently grouped into two locomotor categories: (1) low intensity activity encompassing all

2   activities below 12km/h; and (2) high intensity running that encompasses all running above 12 km/h.

3   The percentage of maximum HR (%HRmax) was calculated by dividing each participant's raw HR

4   scores with their maximal HR value achieved throughout the game, since maximum HR has been

5   shown to be consistently higher during match observations than during lab based tests[19].

6

7   *Video Analysis*

8   The videotapes of each match were subsequently analysed by an experimenter (a qualified

9   football association referee) who edited together all the clips where a foul, or potential foul had

10 occurred. These tapes were then reviewed by two other experimenters, one of whom was a qualified

11 referee, to identify referee decisions when contact occurred between opposing players or a potential

12 handball offense occurred. These included fouls and misconduct incidents, with a range of challenges

13 that required the referee to decide if players' had been tripped, kicked, pushed, charged, jumped, or

14 held, or committed a handball offense (as stipulated by the laws of the game, FIFA, 2007[39]), and

15 they included incidents where the referee apparently missed a decision, as adjudged by the

16 experimenter. We also controlled for the influence of the assistant referees in helping the referee

17 during certain incidents. For example we chose not to analyse offside situations and instead focused

18 on incidents in which the referee alone made the decision. In all except one of the cases (1 of 144) the

19 pitch-side, close-up camera perspective was used to identify tackle and handball incidents.

20   Incidents from the seven games were professionally edited using Final Cut Pro (version

21 3.0.4 for Mac OSX). Each clip was preceded by a title explaining the clip number and included

22 approximately 5-seconds of 'lead-in' of preceding action to orientate the viewer to the context of the

23 game, and each clip finished approximately 1-second after the incident[cf. 15]. Thus the clips ranged

24 from about 6 to 10 seconds in length. Immediately after each incident the volume was dubbed out to

25 remove crowd and player reactions. In cases where the match referee was in the frame he was

26 digitally occluded with a black rectangle, again after the incident had occurred, to ensure that the

1   viewers were not able to see or be influenced by his decision, as the panel's role was to adjudicate on

2   the decision, not the match referee's performance. Subsequent analysis of the referee panel's

3   responses on the quality of each clip and their additional comments revealed that this did not affect

4   the panel's decisions or the number of viewings required. At the start of each set of clips for each

5   game a head title came up on screen depicting the start of the game, with a "half-time" title after the

6   first half clips to allow the viewers to orient themselves to the direction of play.

7   From this editing process 144 foul incidents from the 7 games (approximately 21 per game)

8   were then transferred onto DVD, with each clip indexed so that viewers could easily review each clip

9   by the push of a button. Copies of the DVD were then sent to an independent group of 5 experienced

10   referees. Using a pre-prepared questionnaire this 'expert panel' gave independent decisions for each

11   of the video clips, indicating their decision, the number of viewings required to arrive at this decision

12   and a space to comment on the quality of the clip.

13   We used the number of times that panel members had to view each clip to provide an

14   indirect indication of decision difficulty. It should be acknowledged that it is possible that this

15   difficulty might reflect inadequacies in the video clip rather than the inherent difficulty of assessing

16   the situation. However, none of the clips were reported to be of insufficient quality to be able to make

17   an informed decision. There were also very few critical comments from the panel members about the

18   clip quality and the panel subsequently confirmed that repeated viewings were necessary for more

19   difficult incidents. Therefore it is reasonable to assume that those incidents that were more difficult

20   for the panel members to judge (due to the speed of events, nature of the player contact etc) would

21   also have been more difficult for the match referees.

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23

1   *Statistical Analysis*

2   Various aspects of the GPS and HR data were summarised for each referee and compared between

3   the first and second half with paired sample t-tests. The expert panel questionnaires were collated to

4   identify incidents where a consensus decision had been made. The panel was deemed to have reached

5   agreement when at least 3 of the 5 judges awarded possession to the same team. The uniformity

6   between the judges for each clip was further quantified using correlation. Only the clips in which

7   panel agreement was achieved ($n = 127$) were submitted to further analysis. This sub-set of incidents

8   was contrasted with the match-day referees' actual decisions. 'Accurate' and 'inaccurate' decisions

9   made by the match-day referee were grouped and the GPS and HR data associated with these

10 incidents were compared with independent t-tests. For each dependent variable, the assumption of

11 homogeneity of variance was confirmed prior to any further statistical analyses being conducted.

12 Non-parametric Friedman's analysis of variance was used to compare the differences in decision

13 accuracy in each period of the game. For categorical data (i.e., difficulty of decisions) chi-square tests

14 were employed. The level of statistical significance was set at $P = 0.05$.

15

16   **Results**

17 *Movement and Heart-Rate Analysis*

18   In the present study referees covered 10,323 m on average ($s = 486$ m) during a game.

19 Whilst the referees appeared to cover more ground in the first half than the second half (see Table 2)

20 this difference was not statistically significant ($P > .05$). Despite the trend for distance covered being

21 greater in the first half, the second half of games typically lasted longer than the first half (on average

22 by 1 min 29 sec). The referees' average HR during playing time was 163 bpm ($s = 8.6$ bpm, 84%

23 HRmax), with a higher mean HR in the first half in comparison to the second half ($P < .05$). In one

24 case, the referee's HR was 15 bpm less in the second half, perhaps as a consequence of this referee

25 sustaining a particularly high HR (175 bpm) in the first half.
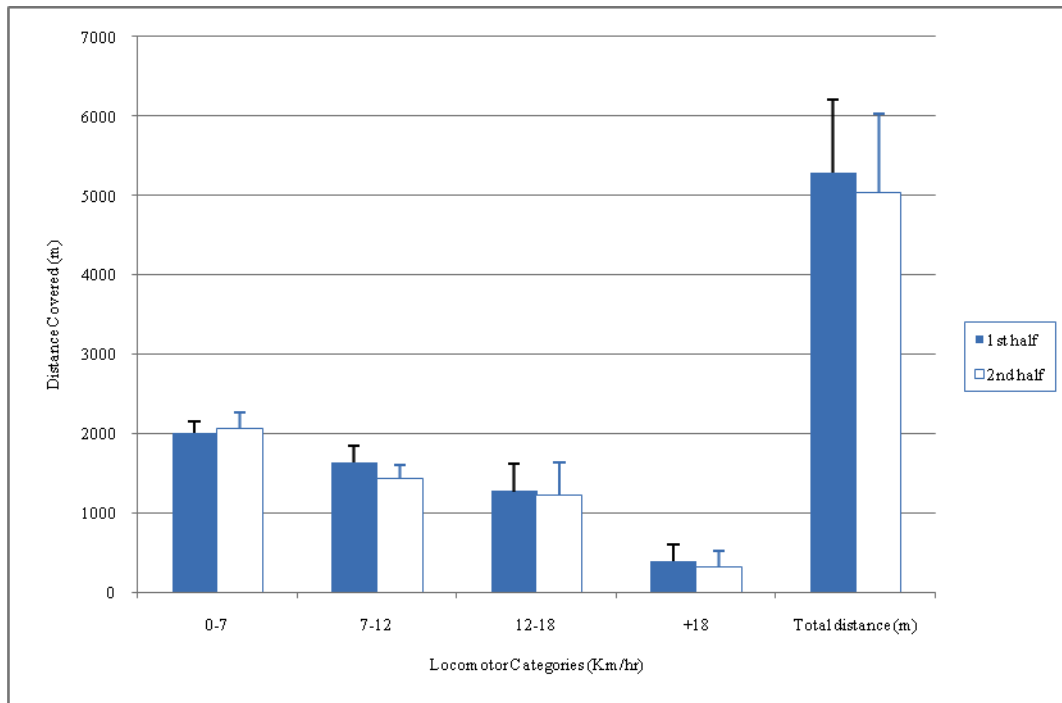
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1   Table 2. Summary of mean locomotion data comparing first and second half performance. * denotes
2   statistically significant difference between first and second half ($P < .05$)

3

4

	First half		Second half		Statistical comparison
	M	SD	M	SD	
Distance Covered (m)	5283	449	5040	525	t(6)=1.97, $P = .10$, d = 0.48
Duration (mins: sec)	47:34	1:03	49:06	0:57	t(6)=2.34, $P = .06$, d = 1.53
*Heart Rate (b/min)	166	7.4	160	9.4	t(6)=2.48, $P < .05$, d = 0.71
Heart rate max (%)	85	3.0	82	5.3	t(6)=2.23, $P = .07$, d = 0.70
Time spent sprinting (%)	3	1.4	2	1.3	t(6)=.86, $P = .43$, d = 0.74
Time spent running (%)	12	3.3	11	3.7	t(6)=1.74, $P = .13$, d = 0.29
*Time spent jogging (%)	22	2.8	20	2.2	t(6)=4.81, $P < .01$, d = 0.79
*Time spent walking (%)	63	4.8	67	6.6	t(6)=3.01, $P < .03$, d = 0.69

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3   Figure 1: Distances covered in different locomotor categories between the 1st and 2nd halves (error
4   bars indicate standard deviation amongst referees).
5

1

2   The referees performed similar levels of high-intensity running in the first and second half

3 (mean time = 30% vs. 31% respectively). Throughout the game referees spent 65% (s = 5.9) of the

4 time standing or walking, 21% (s = 2.8) jogging, 12% (s = 3.4) moderate running and 2% (s = 1.3)

5 sprinting. In the first half, the referees spent proportionally less time standing and walking and more

6 time jogging than in the second half (see Table 2). In terms of distance covered within each speed

7 zone there were similar distributions in each half (see Figure 1).
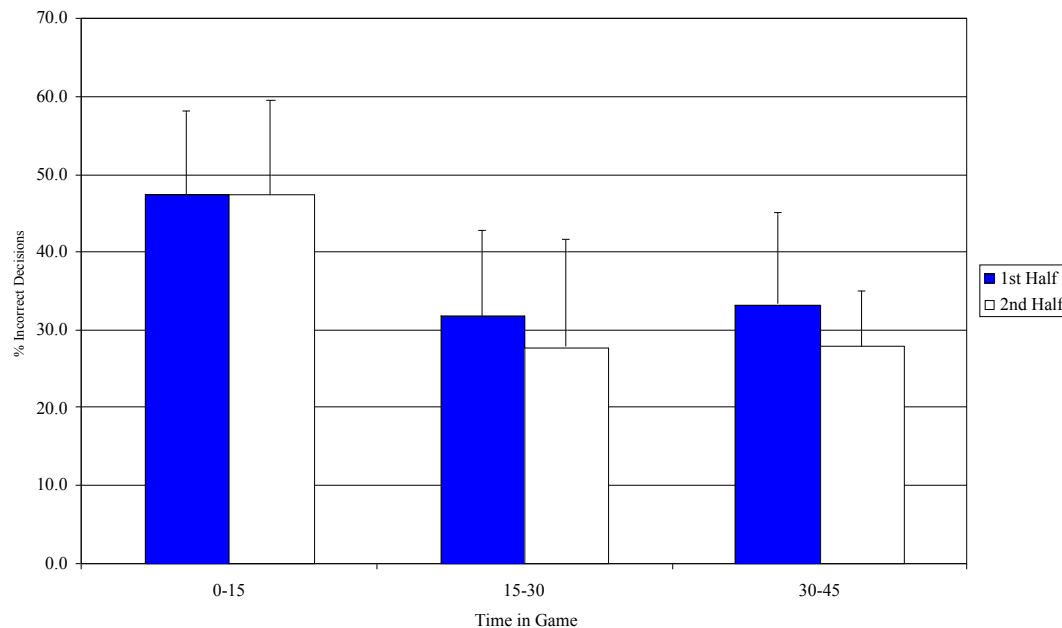
8

9 *Decision Making Analysis*

10   *Expert Panel.*   The coefficient of correlation between the judges' ratings indicated a high

11 degree of uniformity (range = 0.3 to 0.63; all statistically significant at $P < .018$). Agreement was

12 achieved on 88% of the clips (127/144), with an average of 4 out of the 5 experts agreeing on each

13 decision. The difficulty of each decision, which was determined from the number of viewings

14 reported by each judge, was evenly distributed across game time (0-15 mins = 1.7 viewings, 15-30

15 mins = 1.6, 30-45 mins = 1.5, 45-60 mins = 1.7, 60-75 mins = 1.6, 75-90 mins = 1.7).

16   *Accuracy of Decisions.*   The match-day referees made the same decision as the panel on

17 64% of occasions (awarding 81 out of 127 clips correctly). From the occasions where the referee and

18 panel's decision did not concur (n = 46, 36%), 54% (n = 25) arose because the panel saw no

19 infringement and thus the referee erred in penalising the challenge, and 41% (n = 19) were for missed

20 decisions. Therefore, there did not seem to be any strong bias towards over-penalising or under-

21 penalising amongst incorrect decisions.

22   There was also a reasonable balance between the match-day referees and the expert panel in

23 awarding decisions to either the home or away teams. The match-day referees awarded 45 decisions

24 (35%) in favour of the home team and 39 decisions (31%) to the away team and decided there was

25 no-infringement in 43 cases (34%). This finding could possibly suggest a small refereeing bias

26 towards the home side. However, the expert panel who were arguably less susceptible to influential

27 factors such as the crowd, awarded a similar distribution of decisions, i.e., 44 (35%) should have

1   resulted in home free kicks and 37 (29%) should have been awarded to the away team, and 46 (36%)

2   should have been play-on situations. When referees were inaccurate in their decisions, once more this

3   did not seem to bias one team over another as exactly half of the mistakes were given in favour of the

4   home team ($n = 23$) and half in favour of the away team ($n = 23$).

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8   Figure 2. Proportion of incorrect decisions made by match-day referee at different phases of the game

9   (error bars indicate standard deviation amongst referees).

10

11   The referees were less accurate in the opening 15 minutes of each half (1st 15 minutes, mean

12   = 51% correct; 2nd 15 minutes, mean = 69%; 3rd 15 minutes, mean = 70%) than they were at any other

13   period (see Figure 2). The small sample size (n = 7) meant that these differences were not statistically

14   significant. However, the addition of only 4 participants (first half) or 5 (second half) following the

15   same trend would have yielded highly significant ($P < .03$) differences.

1   Of the increased errors in the first 15 minutes, 45% ($n = 9$) were due to penalising when the

2   referee should not have, 20% ($n = 4$) were for not awarding a home free kick and 35% ($n = 7$) were

3   for not awarding a free kick to the away team. Thus, there was no clear pattern of over penalising

4   (45%) or under penalising (55%) in the first 15-minute period of each half.

5   *Speed of Movement*.   The referees' accuracy did not vary with the speed of their movement

6   ($t (125) = 0.08$, $P = 0.9$, Cohen's d =0.02), as the average speed for correct (mean = 6.9 km/hr, $s =$

7   4.3) and incorrect decisions (mean = 7.0 km/hr, $s = 5.3$) was not significantly different.

8   *Heart Rate and Distance Covered*.   There was no significant difference in the average HR

9   between correct (mean = 165.5 bpm, s = 12.5 bpm) and incorrect decisions (mean = 165.6 bpm, s =

10   13.3 bpm; $t(125) = .058$, $P = 0.9$, Cohen's d = 0.01). Similarly, there were no significant differences

11   between the cumulative distance covered (correct mean = 5493 m, s = 2912, incorrect mean = 4709

12   m, s = 2915 m) and the quality of their decisions ($t(125) = 1.46$, $p = 0.1$, Cohen's d = 0.27).

13   *Difficulty of Decisions*.   There was a strong relationship between incident difficulty and the

14   correctness of the match referees' decisions ($\chi^2 (1, 127) = 15.5$, $P < .0001$). For the 33 most difficult

15   incidents (i.e., viewed most often by the panel) match referees' decisions were only 36% correct

16   compared with 75% correct for the remaining 94 clips. There was no statistically significant

17   difference between the most difficult decisions and the others in terms of referees' HR, or

18   locomotion.

19

20   **Discussion**

21   The aim of this study was to examine the DM and locomotor performance of top football referees. In

22   accordance with other investigations[e.g. 26, 31], football referees covered on average nearly 10.5km

23   during a game, with the majority of the distance covered in the first half. There was no difference in

24   the proportion of high intensity running performed although average heart rates dropped from the first

25   half (mean = 166 bpm, $s = 7.4$) to the second half (mean = 160 bpm, $s = 9.4$). Previous research has

26   questioned whether the reduction of physical activity in the second half may be due to referee fatigue

1   or possibly because the tempo of the game decreases as players get tired[e.g. 25, 27, 29, 40]. Taken

2   together the movement and HR scores presented here lend partial support to both interpretations. For

3   example if locomotor activity was limited by referee fatigue in the second half, one might expect

4   higher HR values. However, the referees had higher mean HRs in the first half than the second half.

5   As player work rates were not monitored in the present study, we are unable to confirm that the

6   tempo of the game decreased in the second half. However, the fact that referees heart rates were

7   lower in the second half than in the first half indicates that the referees were conserving energy as

8   they became more fatigued[see also 26]. Further research in which the work-rates of players and

9   officials are measured simultaneously would be necessary to confirm our interpretation of the data.

10   Castagna and D'Ottavio[29] found that elite Italian referees sprint for 13% of match time,

11   run for 25%, jog for 44%, walk for 9%, and move backwards for 9% of the time. However, the

12   present study found a relatively smaller distribution of sprinting and running activities (2% and 12%

13   respectively) with more jogging and walking/standing (21% and 65% respectively). This discrepancy

14   may be explained partly by the slightly different locomotor categories preferred by Castagna and

15   D'Ottavio (e.g. low-intensity running categorised as $< 13km.hr^{-1}$, whereas sprinting was $> 24km.hr^{-1}$)

16   but more likely by the increased total distance covered by the Italian referees (approximately 11.5 km

17   per game). Indeed, the intensity of play in the premier league matches played in Europe and New

18   Zealand may be different which has been shown to influence referee work rate[27].

19   Examination of referees' DM performance revealed figures in line with previous research,

20   with match-day referees achieving on average 64% accuracy from the incidents selected (Fuller *et*

21   *al.*[17]: 70% accuracy; Gilis *et al.*[18]: 60% accuracy). Interestingly, further inspection of the data

22   revealed that referees were on average only 51% accurate in the opening 15 minutes of each half, and

23   70% accurate at all other times. Our analysis suggests that with only a moderately larger sample (e.g.,

24   N = 12 referees) these differences would have been statistically significant. This is an intriguing

25   possibility with important practical applications.

26   Intuitively one might assume that referees begin the game by "laying out their stall," and

27   refereeing strictly to the letter of the law, an approach that is often propounded by referee

1   associations. However, there was no trend towards either over-penalising or under-penalising during

2   the early period of each half. Alternatively, Adams[41] might attribute such a dip in performance,

3   after a period of rest, to some form of warm-up decrement. Anecdotally, the referees' performed no

4   obvious mental warm-up techniques in association with their physical warm-up immediately prior to

5   each half, thus potentially reducing their initial DM performance levels[41]. More likely, these phases

6   of the game present periods of relative instability where teams have yet to settle into established

7   patterns of play, and equally the referee attempts to find appropriate solutions to the game s/he is

8   presented with, by setting boundaries that are synchronous with the game[42]. Regardless of the

9   reasons for poorer performance during the opening period of each half, referees need to ensure that

10   they conduct warm ups that combine physical and mental demands to ensure that they are primed for

11   the challenge that the game is likely to present. It is also worth pointing out that the accuracy data

12   presented are probably underestimates for all the decisions a referee makes in a game as only a

13   selection of incidents were analysed in the present study.

14   Investigation of the balance of both correct and incorrect decisions (i.e., whether the

15   decisions favoured the home or away team) revealed no bias, despite contrary evidence from previous

16   research[e.g. 20, 21]. The match day referee and the experienced panel (who were not susceptible to

17   player or crowd coercion) gave a similar distribution of decisions in favour of the home and away

18   teams.

19   Although research into referees and ARs has shown that speed of movement can affect

20   decision accuracy[22, 35] the current study did not replicate these findings. In the case of referees, the

21   discrepancy might arise due to the different levels of football considered (youth vs. senior) and the

22   fact that our referees participated in the whole match versus 20 minute segments[35]. In relation to

23   ARs perhaps the speed-accuracy decrement arose in Oudejans *et al's* study[11] because the ARs were

24   trying to adjudicate on the relative positioning of players (essentially a perceptual judgment), which

25   became difficult when their own speed increased. Referees are responsible for trying to adjudicate if a

26   foul has occurred or not (i.e., a more complex type of decision drawing upon cognitive judgment) so

27   speed of movement appears to affect these sorts of decisions less. The lack of any simple

28   relationships between DM with speed of movement, HR, and cumulative distance found in the

1   current study indicates that none of these variables in isolation can be used to predict whether a

2   correct or incorrect decision is more likely. Instead, a more complex, multivariate relationship

3   between DM and physical performance is likely to underpin performance in naturalistic

4   environments.

5   As we predicted the match referees were less accurate as the decisions became more

6   difficult, as objectively indicated by the number of repeated viewings required by the expert panel.

7   Given the increasingly common use of television match officials (TMOs) in sports such as cricket,

8   rugby union and rugby league the present study raises some interesting questions applicable in a

9   number of sports. From a DM perspective, it would be of interest to analyse the accuracy of the video

10   official's decision having watched an incident several times relative to the frequency of accurate

11   decisions made from the first viewing (i.e., are gut instincts most often correct?). Also, video officials

12   are relatively impartial to the nuances of the game such as player and crowd reactions. They are

13   required to make relatively passive judgments from a number of different perspectives compared to

14   the active DM processing of the on-pitch referees who may see and hear information that the video

15   official cannot, and can also account for the context of the game [12]. To what extent does this

16   passive presentation of information provide helpful (or conflicting) information from which to inform

17   decisions? Furthermore, does the increasing presence of video officials take some of the control (and

18   players' respect) away from the match-officials? Further research will be necessary to address such

19   issues but for the time-being, it is likely that video officials will remain solely a useful aide to the

20   match official/s for certain types of decisions and sports.

21   Future research should investigate innovative methods to train referee DM whilst

22   maintaining the naturalistic elements of the task. It is possible that officials could enhance their

23   training by viewing multiple video clips of difficult incidents in the way that the TMO does in certain

24   sports. A similar strategy has been shown to be effective amongst rugby football referees, leading to

25   improved judgment accuracy[see 2]. Unfortunately, within the present study we did not collect any

26   data on the subsequent DM performance of those referees who acted as expert judges to ascertain if

27   they benefited from the experience. It would also be worthwhile investigating other training methods

28   that could improve DM. One factor that has been investigated in other performance domains is the

1   time allowed to make each judgment. There is some evidence that time compression in training

2   certain skills (i.e., speeding up the rate at which events occurs) can enhance subsequent performance.

3   This is known as 'above-real-time-training' and has shown some utility in training pilots and air

4   traffic controllers[43]. Similar strategies are used regularly in police and army training, where recruits

5   are progressively placed in stressful real-life situations to 'inoculate' them to extreme DM

6   demands[44].

7

8   Conclusion

9   This is the first study to investigate both the DM accuracy and physical performance of football

10   referees officiating in competitive matches. A number of findings reported (e.g. distance covered, HR

11   and DM accuracy) support research conducted with top-level football referees in other countries.

12   From the small sample of referees who participated, there appear to be no clear simple relationships

13   between activity levels and DM performance. For example, it was anticipated that as referees fatigue

14   their DM performance might deteriorate. However, there were no significant differences between

15   variables such as the cumulative distance covered or HR, and the quality of decisions. These findings

16   should not be construed as implying that the DM and physical performance of the referee are

17   independent. Instead we argue that these processes are intricately connected but their complex

18   relationship is heavily influenced by a number of other factors (such as situational context), which

19   remain to be studied together. Whilst the referees levels of accuracy may seem low at 64% it should

20   be pointed out that only a selection of incidents from the game were analyzed. In fact, the level of

21   decision accuracy found in the present study was exactly in line with those found in previous

22   studies[17, 18].

23   Given such findings and the relative ease of GPS data collection, this investigation

24   highlights the value of such technology as a valuable tool for sports scientists to investigate athletic

25   performance. With further developments in GPS miniaturization, this technology may also present

26   another practical solution to measuring referee and player locomotion in their naturalistic

27   environment without compromising their safety or performance.

28

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