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A comparison of time-motion analysis methods for field-based sports

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Abstract

Purpose. To assess the validity of a digitising time-motion analysis method for field-based sports and compare this to a notational analysis method using rugby union match play. **Method**. Five calibrated video cameras were located around a rugby pitch and one subject completed prescribed movements within each camera view. Running speeds were measured using photocell timing gates. Two experienced operators digitised video data (operator 1 on two occasions) to allow 2D reconstruction of the prescribed movements. **Results**. Accuracy for total distance calculated was within 2.1% of the measured distance. For intra- and inter-operator reliability, calculated distances were within 0.5% and 0.9% respectively. Calculated speed was within 8.0% of measured photocell speed with intra- and inter-operator reliability of 3.4% and 6.0%, respectively. For the method comparison, two 20 min periods of rugby match play were analysed for five players using the digitising method and a notational time-motion method. For the 20 min periods, overall mean absolute differences between methods for percentage time spent and distances covered performing different activities were 3.5% and 198.1 ± 138.1 m, respectively. Total number of changes in activity per 20 min were 184 ± 24 vs 458 ± 48 and work-to-rest ratio's 10.0 / 90.0% and 7.3 / 92.7% for notational and digitising methods, respectively. **Conclusion**. The digitising method is accurate and reliable for gaining detailed information on work profiles of field sport participants and provides the applied researcher with richer data output than the conventional notational method.

Key words

Accuracy, reliability, rugby union, digitising, notational,

Introduction

The quantification of the physical demands of field-based sports is receiving increasing attention as the need for a greater understanding of the work rate profiles of team players has been recognised [1,2,3]. The information gained from these analyses can be used to provide feedback to players and improve the specificity of conditioning programs as well as in a research setting. The most commonly used tool for providing this information is video-based time-motion analysis via notational methods [1,2,3,4,5,6]. This method provides information on the type, frequency and duration of the different activities that players perform; however, a drawback of the notational method is the reliance on subjective interpretation to describe these player activities. The few studies investigating the reliability of assigning activity classifications using notational time-motion methods have reported only moderate intra-observer reliability, with poor reliability when classifying sprint activity [7]. Intra-tester reliability technical error of measurement (TEM) of one such technique has been reported to be between 5.4 and 10.2% for frequency and mean time spent in activities [3].

In order to address some of these problems, a more objective method of analysis is needed, which lessens the decision making required by the investigator. One such method used a combination of manual and automatic player tracking techniques to analyse player movements during handball [8]. Although useful for indoor sports, where video cameras can be positioned directly above the court, this method would be difficult to adapt to the majority of outdoor stadia used for field sports.

The first aim of the present study was, therefore, to present an alternative time-motion analysis method for use in field-based sports, and determine accuracy and reliability. The second aim was to compare the results of the presented time-motion method to a more traditional 'notational' method using elite level rugby union players during match play.

Methods

Part A: Digitising method evaluation

Camera location and calibration

Five video cameras (4 Sony DCR-TRV900E, Japan; 1 Panasonic AG DP2000B, Japan) were positioned around a rugby pitch at predetermined locations (Figure 1) ensuring that all of the playing surface could be viewed. Cameras were placed between 5-8 m above the playing surface and 3-5 m from the nearest sideline. A global 2D cartesian co-ordinate system was constructed with the origin located in one corner of the playing area (Figure 1). For each camera view, four calibration poles (height = 1.0 m) were positioned on the playing surface such that the largest possible rectangle was created for the chosen field of view. The dimensions of each area were measured to within 0.01 m. Images of the calibration poles were recorded.

Prescribed runs

For each of the five cameras, one subject performed a set of runs around the perimeter of the camera's calibration area. To provide data for regions of the pitch outside and at the outer limits of the calibrated areas, runs were also performed around additional circuits within or adjacent to the calibrated areas of cameras 1, 2 and 3 (Figure 1). The subject ran around each area between four and eight times, staying as close as possible to the marked line of the perimeter. Photocell timing gates (Newtest Powertiming System, Finland) were positioned on one length of each rectangle to provide an independent measure of average running speed of the subject (Figure 1). Times were obtained for each occasion that the subject ran through the timing gates.

INSERT FIGURE 1 HERE.

Data Analysis

The top points of each of the four calibration poles were digitised four times each using Peak Motus software (Version 6.0, Peak Performance Technologies, Inc., Colorado) and the average of the image co-ordinates were combined with the known locations to permit 2D camera calibration using the affine scaling technique. For each run, the video data were obtained and a single point (subject's 'hip centre') was digitised at a rate of 1 Hz for the duration of the run. Subsequent reconstruction provided co-ordinates of the subject's position relative to the pitch co-ordinate system every second of each run. The calculated total distance travelled by the subject during each run was obtained by summing the individual displacements for each 1-second time-step. The measured total distance of each run was obtained by multiplying the measured perimeter of each area by the number of times that the subject ran around this area. Estimates for video-derived average speeds were determined by calculating the mean of individual speed estimates for each one-second time step when the subject was running between the photocell timing gates.

Two experienced operators each performed a full analysis of all runs. Operator 1 also performed the analysis for each run on a second occasion, at least 14 days after the first in order to negate recollection of the first analysis. The level of accuracy for total distances was determined by comparing the measured total distances to the calculated total distances from analyses 1 and 2 of operator 1 and the single analysis of operator 2 using Standard Error of the Estimate (SEE), also presented in percentage as Coefficient of Variation (CV) [9,11]. A comparison of speed estimates was obtained by evaluating the speeds derived from the photocell timing gates against those produced from the speed-time data for both analyses by operator 1 and the analysis of operator 2 using SEE and CV. Intra-operator reliability was determined by comparing the calculated distances and speeds from analyses 1 and 2 of operator 1. Inter-operator reliability was established by comparing the calculated distances and speeds of operator 1, analysis 1 and operator 2. Reliability for both intra- and inter-operator results was measured using Typical Error of Measurement (TE), also expressed in percentage as Coefficient of Variation (CV) using the methods described by Hopkins [10,11]. Based on the categorisation of McInnes *et al.* [12] CVs were described as good (<5%), moderate (5-9.9%) and poor (>10%).

Part B: Player movement analysis

Digitising method

The cameras were set up as described in Part A and camera calibrations were carried out prior to the beginning of the match. The entire duration of the match was recorded for each view. Five players (two forwards and three backs) from two English Premiership matches played at the same venue were used for the analysis.

Videos of the matches were time-coded to provide comparison reference times across different views and captured as video files. Image-based tracking of the players was carried out using the same system as described in Part A. When the player left the view of one camera, the time was noted and tracking was continued at the corresponding time point in the appropriate camera view. Real space co-ordinates were reconstructed by combining digitised co-ordinates and camera calibration information. The one-second time displacements derived from the reconstructed data were smoothed using a local neighbourhood averaging method (Hanning) and categorised into activity classifications. Discrete movement classifications were constructed based on derived speed estimates and using boundaries similar to those described by Castagna and D'Ottavio [13]:

1. Standing/non purposeful movements (0-0.5 $m.s^{-1}$)
2. Walking (0.5-1.7 $m.s^{-1}$)
3. Jogging (1.7-3.6 $m.s^{-1}$)
4. Medium-intensity running (3.6-5.0 $m.s^{-1}$)
5. High-intensity running (5.0-6.7 $m.s^{-1}$)
6. Maximal speed running (>6.7 $m.s^{-1}$)

A further classification of 'static exertion' was used to group scrums, rucks, mauls, line out lifts and tackles. Bouts of static exertion were recorded during the digitising process at the appropriate time points of the match so that final calculations could include time spent in static exertion, overwriting other movement classifications at these times.

Notational method

During the two matches, three additional digital video cameras (Sony DSR-PD100AP, Japan) were used to follow individual players for defined periods of the match. These 'roaming' cameras were operated from positions adjacent to fixed cameras 1, 2 and 3. Each 'roaming' camera followed two players for 20 min periods on two occasions during the match: 0-20 and 40-60 min or 20-40 and 60-80 min. The zoom function was used to maintain an approximate radius of 5 m about the player of choice in the field of view. The five players selected for analysis using the digitising method were also tracked using the notational method to allow method comparison.

Notational time-motion tracking was achieved using the "The Observer" software package (Version 4.0, Noldus IT, Netherlands). The activity classifications were the same as those used in the digitising method:

1. Standing/non purposeful movements
2. Walking – player at least one foot in contact with the ground at any time

3. Jogging – short flight phase
4. Medium-intensity running – as jogging but with a more pronounced arm swing
5. High-intensity running – elongated stride
6. Sprinting/maximal speed running – maximal effort

An experienced operator viewed player activity patterns for each 20 min period on a large television monitor, and coded the initiation and completion of each discrete bout of activity using assigned keys on a standard keyboard. The computer software recorded the duration and type of activity and calculated the percent duration spent in each activity classification. Distances covered in each activity category were estimated by multiplying the time spent in each category by the median of the velocity used in classifying activities for the digitising method (walking = 1.1 $m.s^{-1}$; jogging = 2.65 $m.s^{-1}$; medium-intensity running = 4.3 $m.s^{-1}$; high-intensity running = 5.85 $m.s^{-1}$; sprinting = 6.7 $m.s^{-1}$).

Total distances and percentages of total distance travelled in each activity classification were calculated for each 20 min period. The percentage of match time spent in each activity classification was calculated for the digitising and notational methods as well as the total number and average durations of activities. Work and rest were calculated based on the amount of time spent in high (work: movements > 5.0 $m.s^{-1}$ and static exertion) and low (rest: movements < 5.0 $m.s^{-1}$) intensity exercise [13]. Data are presented as mean ± standard deviation.

Results

Part A: Prescribed runs, Digitising method

Total measured distances covered during prescribed runs in each camera view ranged from 302.4 m to 635.0 m. The range of speeds determined by the photocell timing method was between 2.5 $m.s^{-1}$ and 5.3 $m.s^{-1}$. Results for SEE and CV between the measured and calculated distances and speeds are shown in Table 1. Results for intra- and inter-operator reliability are shown in Table 2. Using data from the digitising method as an example, the total distance travelled by one player in the current study was 6126 m. Applying the CV of 2.1% between measured and calculated total distance (operator 1, analysis 1; Table 1) returns a possible range of 5997-6255 m.

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

Part B: Digitising vs Notational method

Mean differences and Mean Absolute Differences (MAD) between the digitising and notational method are presented in Table 3. The percentage of time spent performing work and rest activities were 10.0 ± 6.3% vs 7.3 ± 5.6% and 90.0 ± 6.3% vs 92.7 ± 5.6% for the notational and digitising methods, respectively. The difference between methods for time spent in work reflects estimates of 5.8 min and 8.0 min of work according to the digitising and notational methods, respectively; a difference of 27.5%.

INSERT TABLE 3 HERE

For a 20 min period, mean distance travelled was 1554 ± 329 and 1446 ± 163 m for the notational and digitising methods, respectively. Over the ten trials, the differences in estimated total distances between the notational and digitising method for each 20 min period ranged from -191.6 m to +444.1 m with a mean absolute value of 198.1 ± 138.1 m. This mean absolute value extrapolated over an 80 min match, results in a mean difference in distance covered of 792 m but could be as large as 1500 m in some cases.

The mean number of changes in activity per 20 min period was 184 ± 24 and 458 ± 48 for the notational and digitising methods, respectively. Speeds calculated for each activity (except sprinting) in the notational method (median of the speed range assigned to the categories in the digitising method) were greater than the mean speeds of each category in the digitising method with a MAD of 0.13 $m.s^{-1}$.

To assess the intra-operator reliability for the notational method, all 10 trials were re-analysed at least one month later. The TE between analysis 1 and analysis 2 ranged between 0.1-1.8% across the seven activity categories for the percentage of time spent in the given activity category.

Discussion

This study sought to establish the accuracy and reliability of a digitising video-based method of movement analysis for field-based sports. The results of reconstructed participant positions during the evaluation process were compared to measured distances and speeds. When compared to measured or calculated values, the method shows good accuracy against measured distances, moderate accuracy against calculated speeds and good and moderate reliability for intra- and inter-operator analysis, respectively. This method was also compared with a notational time-motion method. This comparison demonstrated differences in proportions of time spent in different activities, leading to potentially large discrepancies between methods when these values are converted to distances covered.

Part A: Digitising method evaluation

The good intra-operator reliability for total distance covered (CV of 0.5%) in the current study compares favourably to those of previous studies for duration and frequency of activities [3,7,12,14]. However, it must be acknowledged that these previous studies investigated match play, which would include rapid changes of direction, rather than the controlled experimental set-up, consisting mainly of linear running, used in the present study. Limited information is available from previous studies regarding inter-operator reliability. Compared to the error of less than 1% for total distance travelled in the present study, one time-motion analysis on rugby union refereeing reported a 'good' (r = 0.97) reliability [15] whereas a study on soccer work profiles reported a variation of not more than 4% when comparing total time spent by the subject in any activity classification [13]. The results of the current study for the digitising method provide confidence that when analysing player movements on separate occasions, or if a second experienced operator performs the analysis, only a small difference may be a result of operator error.

The results of the speed estimates obtained demonstrate moderate accuracy and reliability when compared to the criterion measure of the photocell timing gates. Another study comparing the use of player tracking to a reference velocity reported root mean square (RMS) errors of 0.07-0.20 $m.s^{-1}$ (2.4-6.8%) [8]. These data were collected over a smaller playing area than in the present study and in an indoor facility allowing camera positions on the roof directly above the playing area. Compared to intra-operator reliability for speed determination (CV of 3.4%) in the present study, McLean [5] reported standard deviations of the difference of 0.09 s and 1.3 m for intra-observer reliability for the calculation of timed runs and estimated distances. Equating these errors [5] to actual speeds, a player travelling 20 m in 4 s (5 $m.s^{-1}$) could have a calculated speed between 4.6 and 5.5 $m.s^{-1}$, assuming an error of 1 standard deviation. These values equate to an approximate error of up to +10% and -8% suggesting that speed cannot be accurately determined using the method of Mclean [5].

Part B: Method comparison

Some of the discrepancies in the percentage of time spent in different activities between methods can be attributed to the fact that seven activity classifications were defined. This increases the difficulty in selecting the appropriate activity than if fewer classifications are used. Differences in the percentage of time spent in different activities results in disparate work-to-rest ratios for the two methods which is mainly attributable to differences in the time spent in static exertion. This is likely to be a result of the different footage used to derive these data, since static exertion was analysed in the same way for both methods. The 27.5% greater time calculated to be spent in work in the notational method may lead to practitioners using different approaches in the physical preparation of players. With an emphasis on training specificity, conditioning plans may be designed based on different average durations and frequencies of work activity. This finding particularly highlights the care which should be taken in the comparison of the physical demands on players from the same sport when different analysis techniques have been used.

To calculate distance travelled using the notational method, an assumption of constant speed within a given activity category is required, and this was taken as the median of the speed ranges in the digitising method. Calculating mean speeds in each of the digitising activity categories showed that these were generally lower than the median of the speed range, providing some explanation for the greater distances travelled by players using the notational method. Previous studies have not reported the reliability of total distances covered but rather total time, frequency and mean duration in discrete activity classifications. These may then be combined with estimates of running velocity for each activity mode to calculate distances covered. Average intra-operator differences of time spent in different activities have been 6.6% [12], 8.3% [7] and 8.1% [3]. As demonstrated in the current study, these errors combined with the median speed for each activity classification appear to result in greater overall error than the digitising method if the estimated speed used does not accurately represent the mean of the actual speed. The current study shows that distances travelled in medium running, high running and sprinting in particular, were greater when using the notational method. This is of particular importance, since quantifying high intensity exercise is one of the most informative outputs from the analysis of match play, and is likely to have the greatest impact on the development of training and conditioning programmes as well as being of greatest interest to applied researchers.

The greater percentage of time spent sprinting in the notational method may be due to the digitising method categorising exclusively on speed of movement. A sprint in team sports has been reported to last between 2-3 seconds [16] which, from a standing start, is insufficient time to attain maximum speed. Hence, players may be performing at maximal effort, but are accelerating and do not reach speeds defined by the sprint category when using the digitising method. In contrast, using the notational method, the player could be judged to be running with maximal effort and therefore classified as sprinting. The greater number of changes of activity per 20 min period using the digitising method supports this, demonstrating that this method is sensitive to players accelerating and decelerating through activity categories. The number of changes of activity highlights the physical demand placed on games players in overcoming inertia during acceleration and large eccentric loads induced by deceleration. Based on this information, coaches can make informed decisions about the incorporation of intermittent sprint activity into training regimes, with perhaps less emphasis on longer sprints. Repeated sprint ability in team sports is a critical aspect of performance and it is therefore crucial that it is determined accurately.

Methodological considerations

For the digitising method, benefit would be gained from maximising the camera tilt angle in order to reduce perspective errors. Co-ordinate reconstruction would also be improved through using a greater number of calibration points in each field of view [17]. Any error in the camera calibration process will primarily introduce systematic error without markedly altering estimates of distance and speed, but these differences may arise from random errors during the image digitising process. However, given that an identifiable body landmark is digitised, there is likely to be little variation from an experienced operator, as shown by the reported inter-operator reliability. In contrast, the notational method requires the operator to make a greater number of decisions regarding mode, frequency and duration of activities [1,3,7,14,16]. These decisions are more prone to variability than those in the digitising method. In this context, the greater sensitivity of the digitising method offers improved scope for investigating issues such as the influence of playing position on movement patterns in team sports. Other technologies, such as Global Positioning Systems (GPS) can be used to acquire time-motion data during athletic competition similar to that presented; however the size of the device that players must wear makes this system more intrusive for rugby union match play.

Application and conclusion

From a practical perspective, the digitising method is labour intensive, taking approximately 8 h to produce data for one player for a whole match. This is restrictive in terms of providing feedback to performers, whereas the notational method is less time-consuming, making it potentially more appropriate for feedback purposes. However, for research applications, the digitising method would appear to be preferable in terms of the specificity of information which can be acquired. Accurate estimates of speeds and distances travelled during match play allow for a more detailed study of fatigue in an applied setting. For example, it will be possible to examine the effects of brief periods of high intensity activity on subsequent activities, as well as the influence of the entire match on activity in the final minutes. Further to this, the role of replacements can be closely studied, in terms of their performance during the closing stages of a game. The increased understanding gained from such analysis can also inform the design of specific exercise protocols used by the researcher, thus partly overcoming the difficulty of replicating specific physical demands of team sports in a controlled research environment.

The digitising time-motion analysis method for field-based team sports provides accurate and reliable data for distances covered and movement speeds. This can be attributed to the minimally subjective nature of this method. Although analysis is labour intensive, the application of this method yields results that can help researchers assess performance for as many players as necessary and develop comprehensive work-profiles of match play. Whilst notational methods are adequate for player feedback, the digitising method is a better tool for developing an understanding of the specific physical demands of team sports.

References

1. Deutsch MU, Maw GJ, Jenkins D, and Reaburn P. Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *J Sports Sci.* 1998;16:561-570

2. Reilly T, and Thomas V. A motion analysis of work rate in different positional roles in professional football match-play. *J Hum Move Stud*. 1976;2:87-97.

3. Spencer M, Lawrence S, Rechichi C, Bishop, D, Dawson B and Goodman, C. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. *J Sports Sci*. 2004;22:843-850

4. Treadwell PJ. Computer-aided match analysis of selected ball games (soccer and rugby union). In T.Reilly, A.Lees, K.Davids and W.J. Murphy (eds.), *Science and Football* (pp. 261-264). London, England: E. and F.N. Spon, 1988;282-7

5. McLean D. Analysis of the physical demands of international rugby union. *J Sports Sci*. 1992; 10:285-296.

6. Duthie G, Pyne D and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. *J Sports Sci*. 2005;23:523-530

7. Duthie G, Pyne D and Hooper S. The reliability of video based time motion analysis. *J Hum Move Stud*. 2003;44:259-272

8. Pers J, Bon M, Kovacic S, Sibila M, and Dezman B. Observation and analysis of large-scale human motion. *Hum Move Sci*. 2002;21**:**295-311.

9. Hopkins WG. Analysis of validity by linear regression (Excel spreadsheet). *A new view of statistics. sportsci.org: Internet Society for Sport Science, sportsci.org/resource/stats/xvalid.xls.* 2000a

10. Hopkins WG. Reliability of consecutive pairs of trials. (Excel spreadsheet). *A new view of statistics. sportsci.org: Internet Society for Sport Science, sportsci.org/resource/stats/xvalid.xls.* 2000b

11. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med*. 2000c;30**:**(1) 1-15.

12. McInnes SE, Carlson JS, Jones and McKenna MJ. The physiological load imposed on basketball player during competition. 1995;13:387-397.

13. Castagna C. and D'Ottavio S. Effect of maximal aerobic power on match performance in elite soccer referees. *J Strength Cond Res*. 2001;15 (4):420-425.

14. Bangsbo J, Norregaard L, and Thorso F. Activity profile of competitive soccer. *Can J Sport Sci*. 1991;16:110-116.

15. Martin J, Smith N, Tolfrey K. and Jones AM. Activity analysis of English premiership rugby football union refereeing. *Ergonomics*. 2001;15(4):420-425.

16. Spencer M, Bishop D, Dawson B. and Goodman C. Physiological and metabolic responses of repeated-sprint activities. *Sports Med*, 2005;35 (12) 1025-1044

17. Brewin MA and Kerwin DG. Accuracy of scaling and DLT reconstruction techniques for planar motion analyses. *J Appl Biom*. 2003; 19(1):79-88.

Figure 1. Depiction of prescribed run perimeters with locations of photocells (denoted by) on pitch. Corresponding camera for each view matched by number. Cartesian co-ordinate system origin shown by 0,0.

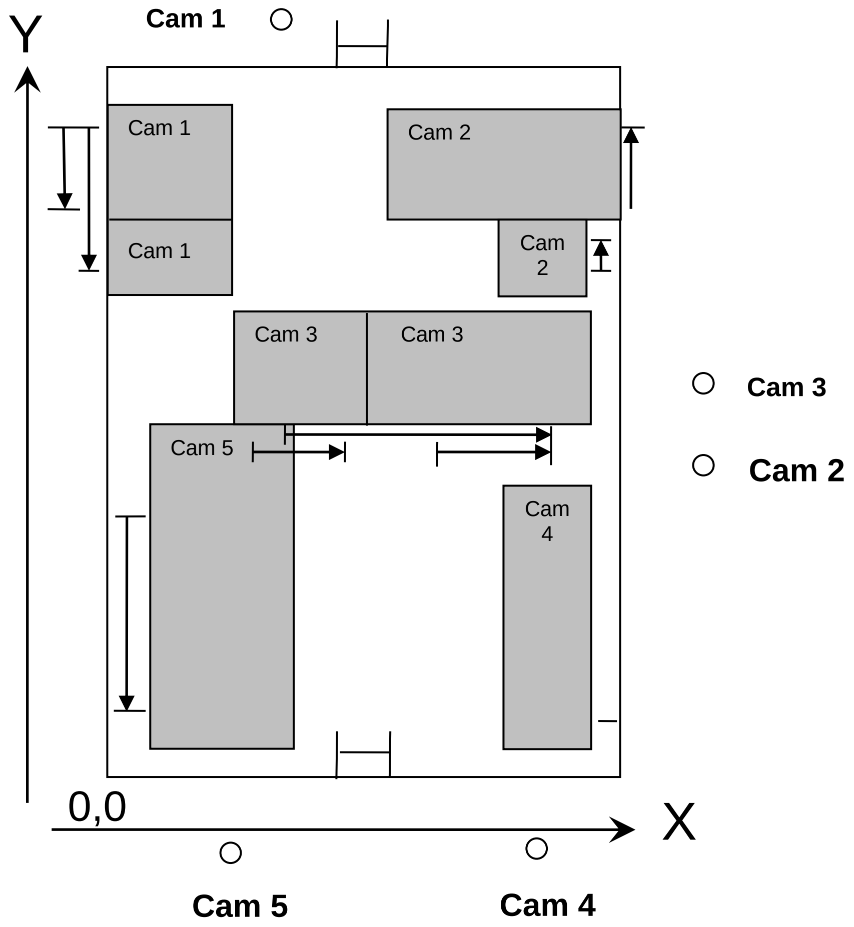

Table 1. Comparison of measured vs. calculated distances and photocell vs. video-based methods for the determination of subject speed.

	Operator 1		Operator 2
	Analysis 1	Analysis 2	
	Total distances (m)		
SEE (m)	7.4	6.0	7.1
CV (%)	2.1	1.6	1.8
	Speed ($m.s^{-1}$)		
SEE ($m.s^{-1}$)	0.3	0.3	0.2
CV (%)	8.3	7.3	6.7

Analyses of Operators 1 and 2 are compared with measured differences using the Standard Error of the Estimate (SEE), also expressed as the Coefficient of Variation (CV).

Table 2. Intra- and inter-operator reliability for calculated total distances and speeds.

	Total distance (m)		Speed ($m.s^{-1}$)	
	Intra	Inter	Intra	Inter
TE	1.7	4.2	0.1	0.2
CV (%)	0.5	0.9	3.4	6.0

Operator 1, analysis 1 vs analysis 2 (intra) and Operator 1, analysis 1 vs Operator 2 (inter) measured using Typical Error of Measurement (TE), also expressed as the Coefficient of Variation (CV).

Table 3. Percentage differences in time spent in, distances covered during, and average duration of each activity classification between the digitising method and the notational method.

Activity	Time spent		Distance travelled		Average duration	
	Mean difference	Mean absolute difference	Mean difference	Mean absolute difference	Mean difference	Mean absolute difference
Standing	+3.3	7.0	+2.3	2.6	+6.30	6.30
Walking	-4.8	6.8	-3.3	7.9	+5.64	5.64
Jogging	-4.2	4.2	-5.2	6.0	+2.13	2.13
Medium running	+2.9	2.9	+11.3	11.3	+2.41	2.41
High running	+0.3	0.6	+1.6	3.1	+1.25	1.25
Sprinting	+0.1	0.3	+0.2	1.7	-0.31	1.11
Static exertion	+2.4	2.7	-	-	+1.97	1.97

For Mean difference, positive values denote greater values when using the notational method and negative values denote greater values when using the digitising method.