International Journal of Performance Analysis of Sport
2010, 10, 270-278.

The relation between movement velocity and movement pattern in elite soccer

Malte Siegle and Martin Lames

TU Munich, Faculty of Sport Science, Connollystraße 32, 80809 München

Abstract

The aim of the study was to analyse the inter-individual differences concerning the velocities at which changes in movement pattern occurred. During the FIFA World Cup Final in 2006 20 players were observed. For every player the individual velocity boarders were obtained for the movement patterns walking, jogging, cruising and sprinting. Comparisons were done between common velocity boarders and the individualized thresholds. Significant differences (p < .001) were found for all three movement patterns. Therefore analysis based on generalized and fixed transition velocities should be reconsidered.

Key words: locomotive movement

1. Problem

Modern game analysis in soccer is commonly based on positional data. Multiple camera systems provide these data, from which several measures of performance can be calculated, such as running distance and movement velocities. More specifically this study addressed the conventional methods for analysing the movement velocities of players.

A common method used in performance analysis which is based on positional uses fixed velocity intervals to represent different movement patterns. Many studies have used this method in soccer analyses (Clark, 2010; Bradley*et al*., 2009; Di Salvo *et al*., 2007; Impellizzeri *et al*.; 2006; Rampinini *et al*., 2007; Bangsbo *et al*., 1991; Mohr *et al*., 2003).

The velocity intervals used in these studies were fixed boundaries generally used for all players. No differences were made for players. For example, the transition between walking and jogging were 2 $m.s^{-1}$. Because of individual variability this method may not accurately represent the real movement pattern of any given player. In order to assess the validity of this method, the current study compared the classification of movement patterns by experts with those which were derived from velocity intervals.

2. Method

2.1. Dataset

The data were taken from the FIFA World Cup Final in 2006 between Italy and France. Positional data of each player were obtained by image detection techniques developed in the research project ASpoGAMo (Beetz *et al*., 2009). The investigations are in agreement with the ethical convention of the university at which the study was completed.

2.2. Statistical analysis

All statistical analyses were conducted using SPSS for Windows Version 13.0 (SPSS Inc., Chicago, IL, USA). All results never mind reported as means and standards deviations (mean ± s) calculated by conventional procedures unless otherwise stated. Before using parametric statistical test procedures, the normality of the data was tested. A one-way analysis of variance (ANOVA) was used to test for differences in mean velocities of each movement pattern. To check differences between players and movement patterns, Duncan's t-Test was applied.

2.3. System overview

The match was filmed from a position behind one goal at a height of about 20 meters, so that the whole pitch was in view. A high-definition camera was used, providing a MPEG-file. After fitting the field model, the ASpoGAMo system detected and tracked players using three segments of a single player: shirt, trousers, and legs, the software developers call these segments "blobs". The tracking frequency used was 25 Hz. Tracking errors were automatically corrected using the Multiple Hypotheses Tracker which was integrated in the software package (MHT, Beetz *et al*., 2006). Finally, any errors which still existed, for example, players being misidentified, were manually corrected.

2.4. Data collection and eligible frames

Only frames in which the players moved linearly (no extreme changes of direction) without the ball and without being influenced by an opponent were chosen for analysis. Additionally, in order to have clearly defined movement patterns, no frames were chosen in which a player changed his movement pattern. One may argue that this does not correlate with the character of the game but it was used in order to get clear information about the movement pattern, which was the main purpose of the study.

2.5. Observation of movement patterns

The movements of the 20 outfield players were observed by an experienced observer, who has analysed more than 75 soccer games. Frames where they moved with one of four movement patterns (walking, jogging, cruising and sprinting) were identified sequentially from the beginning of the match. Because these patterns were not derived from movement velocities, but from video frames, qualitative definitions had to be determined. The patterns of movement were operationally defined in accordance to the Bloomfield movement classification (Bloomfield *et al*. 2004):

- Walking: One foot has contact to the ground; there is no flight phase with two feet off.
- Jogging: Moving at a slow monotonous pace.
- Cruising: Manifest purpose and effort, usually when gaining distance.
- Sprinting: Maximal effort, rapid motion.

Frames in which the players were sprinting without the ball and without opponent influence could not be observed in the needed number for analysis; therefore a combined category cruising/sprinting was introduced. For each of the three remaining patterns and for each player 50 frames were collected, giving a total of nearly 3000 frames. In order to be included in the sample, players should clearly exhibit the defined movement pattern for at least one second, not carrying the ball and not being influenced by an opponent. For economical reasons frames were not picked on a random basis but eligible frames in the video were collected in a sequential manner until the required number of 50 was achieved per player and category.

Observational methods are, by definition, subject to errors committed by the subjective observer. Accepted procedures were taken to minimise these errors (Lames, 1994; Hughes and Franks, 2004). In this study there were two sources of observational errors: a) eligibility of the frame for the analysis and, b) classification of the movement pattern. To control for these errors one player and one sixth of the game (elapsed time) were chosen at random and two independent observers assigned the movement pattern to each frame. Results for the first type of error showed that the two experienced observers identified 91 and 100 eligible frames, respectively, of which 89 were in agreement for selection. This results in a percent agreement of 87.3%. Since the categories were unbalanced, kappa was calculated according to Gwet (2002) and resulted in kappa=.855, meaning acceptable agreement. The second kind of error was controlled by comparing the judgements on movement pattern of two independent observers in the 89 selected frames. For this source of error there was no disagreement between the observers (percent agreement 100%, kappa =1.00). Although frames were selected when the player showed a clear movement pattern, this is still somewhat surprising because we had transitions between the patterns. In this case, the observers declared the frame (length=1 second) as not eligible and assigned the frames before and after that frame to the respective pattern. This procedure was shown to exhibit an efficient control of the second type of error.

3. Individual speed thresholds

Using mean and standard deviation the normal distribution for each movement pattern and each player was calculated (20*3 distributions). Because it was a crucial assumption of this study that speed distributions of movement patterns are normally distributed, this was statistically tested by Kolmogorov-Smirnov-Tests (K-S) and graphically inspected for distribution and outliers with Q-Q-Plots. The significance levels for the K-S statistics obtained were over 0.20 in 56 (93.33%) of the 60 cases. In only one case a K-S significance level lower than .05 (Player 13, jogging, p=0.02) was found. Together with the results of the graphical inspections, the assumption that the empirical distribution of 50 velocities per player and movement pattern can be approximated with a normal distribution was justified. Assuming validity for this representation of the speed distributions, the most obvious estimate, or operational definition of speed boundaries between two movement patterns, was the speed at the intersection point of the two distributions. Figure 1 shows the three normal distributions with the two relevant intersection points for Player 10. These points were taken for individual speed thresholds between the movement patterns.

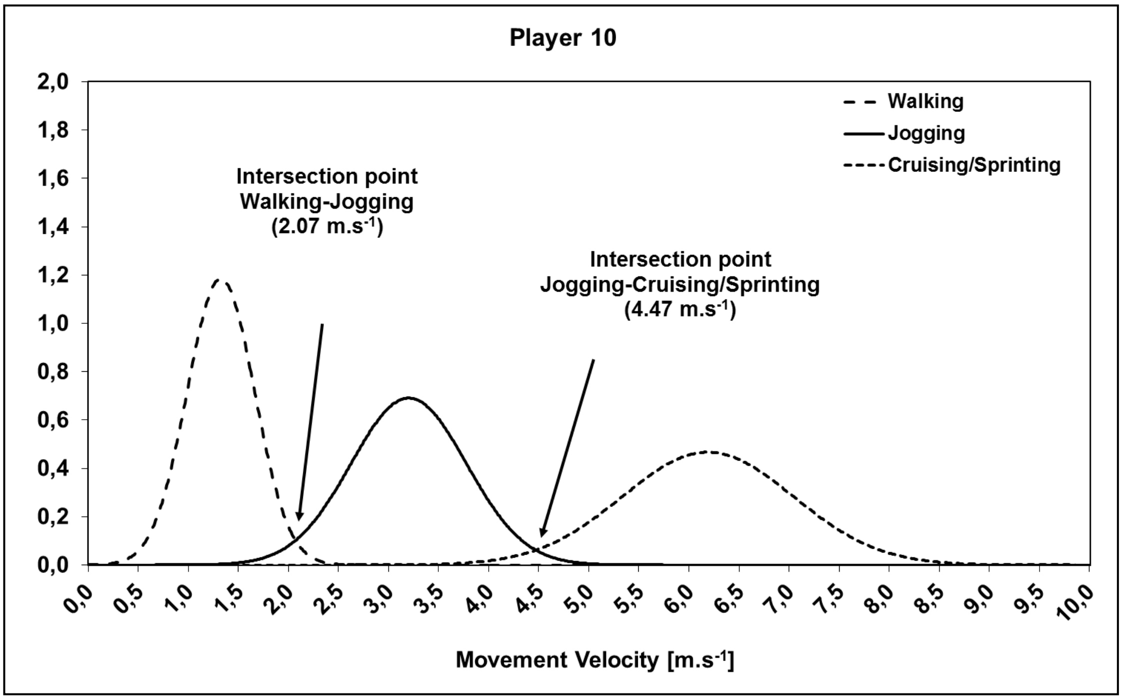

Figure 1: Individual speed thresholds of player 10.

4. Comparison of general to individual velocity intervals

In order to clarify the differences between general and individual velocity intervals, both methods were used to calculate the distance run in each movement category. The intervals of the general method were the ones used in Bradley *et al*. (2009). The individual velocity intervals were observed from the analysed game. Distances run were calculated from the positional data of the observed match.

5. Results

5.1. Individual velocity intervals

The results for the individual velocity intervals for the 20 outfield players are shown in table 1. Transitions between walking and jogging occurred at an average speed of 2.06 $m.s^{-1}$ (SD=0.14 $m.s^{-1}$) and those between jogging and cruising & sprinting at 4.53 $m.s^{-1}$ (SD = 0.34 $m.s^{-1}$). The variation coefficients increased with velocities from 6.79 % for walking/jogging and 7.49 % for the transition between jogging and faster patterns of displacement. This means that there is considerable variation in threshold velocities between players. An ANOVA comparison between the mean velocities of every movement pattern showed significant differences (Walking: F=5.526, df=19. 981, p=.000; Jogging: F=7.413, df=19. 981, p=.000; Cruising/Sprinting: F=8.791, df=19. 730, p=.000). Duncan's t-Test revealed several significant differences between players (table 2).

Table 1: Individual velocity intervals.

player	walking	jogging	cruising & sprinting
4	0.00 - 1.82	1.83 - 4.26	> 4.26
5	0.00 - 2.05	2.06 - 4.32	> 4.32
7	0.00 - 2.22	2.23 - 4.37	> 4.37
8	0.00 - 2.05	2.06 - 4.37	> 4.37
9	0.00 - 2.09	2.10 - 4.45	> 4.45
11	0.00 - 2.11	2.12 - 4.51	> 4.51
12	0.00 - 1.98	1.99 - 4.60	> 4.60
16	0.00 - 2.03	2.04 - 4.84	> 4.84
18	0.00 - 2.03	2.04 - 4.85	> 4.85
19	0.00 - 2.14	2.15 - 5.11	> 5.11
1	0.00 - 2.02	2.03 - 3.95	> 3.95
2	0.00 - 1.83	1.84 - 4.03	> 4.03
3	0.00 - 1.93	1.94 - 4.10	> 4.10
6	0.00 - 1.92	1.93 - 4.32	> 4.32
10	0.00 - 2.07	2.08 - 4.47	> 4.47
13	0.00 - 2.16	2.17 - 4.60	> 4.60
14	0.00 - 2.02	2.02 - 4 .70	> 4.70
15	0.00 - 2.17	2.18 - 4.70	> 4.71
17	0.00 - 2.20	2.21 - 4.84	> 4.84
20	0.00 - 2.43	2.44 - 5.23	> 5.23

Table 2. T-Test for players and mean velocities per pattern

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		W																	CS	J
2	W		W			W	W	W		CS	W	CS	CS;W	CS	W	CS	W		CS	CS/W
3		W																		J
4																J		J		J
5																			CS	
6		W														J		J		J
7		W																		
8		W																		
9																			CS	
10		CS																		
11		W																		
12		CS																		
13		CS/W																		
14		CS																		
15		W																		
16		CS		J		J														
17		W																		
18				J		J														
19	CS	CS			CS				CS											
20	J	CS/W	J	J		J														

5.2. Comparison between general to individual velocity intervals

Results for the comparison between distances ran in the different movement patterns are shown in table 3. For each of the three observed movement patterns and the two different methods the absolute are illustrated. For example player 2 showed differences of 837m for walking, 535m for jogging and 230m for cruising/sprinting.

Table 3. Comparison between general and individual velocity intervals (*=player was substituted). (standing and walking were taken together as walking, jogging and running were taken together as jogging, high-speed running and sprinting were taken together as cruising/sprinting).

	walking			jogging			cruising & sprinting		
player	general	individual	difference	general	individual	difference	general	individual	difference
1*	3823	3591	232	2192	2093	99	298	311	13
2	5544	4707	837	3213	3748	535	614	384	230
3*	3878	3371	507	1676	1778	103	511	467	44
4	5699	4674	1025	2979	3419	441	611	483	127
5	5996	5473	523	2886	3049	162	718	426	292
6	5576	4679	896	1457	1636	180	312	203	109
7	5939	5575	364	1863	1570	292	356	227	129
8	5722	5154	568	1771	1760	11	342	247	95
9	5631	5216	415	1980	2004	24	439	243	196
10*	5960	5502	458	2698	2899	201	906	560	346
11*	3490	3223	267	1425	1384	41	272	156	116
12	5992	5365	628	1328	1513	184	454	261	193
13	5833	5507	326	2912	2945	34	830	455	375
14	6096	5511	585	1912	2118	207	585	283	302
15	5539	4920	620	1138	1084	54	301	130	171
16	5839	5353	486	2682	2944	262	765	368	397
17	5934	5509	424	1637	1651	14	434	145	289
18	6013	5296	717	1656	1845	189	470	203	267
19	5954	5566	387	2082	2186	104	531	195	336
20	5983	5998	15	2312	1971	341	615	163	452

6. Discussion

Since the introduction of computerised semi-automatic detection of players' positions in soccer, it has become a standard procedure to characterize the running performance of the players with frequencies and distances the players cover with certain movement patterns, such as: walking, jogging, cruising and sprinting. Originally, these movement patterns were derived from speed intervals. Therefore, a player moving with a certain speed was always assigned to the same movement pattern classification. The advantages of this method are that with positional data at hand, these classifications are readily available, and it is also an objective method to assign a movement pattern at every point in time.

Our criticism of this method is that detailed validation studies are hard to find. Van Gool *et al*. (1988) and Bangsbo *et al*. (1991) measured the velocities of instructed movements with certain patterns. One may assume that there is more variation under match conditions, but in most other studies, speed thresholds were only assumed by convention and not confirmed by empirical trials.

In this study movement patterns of players in a match were observed. In clear cases (linear movements without ball and opponent) their velocities in these frames were recorded. For each player and movement pattern 50 frames were sampled. Velocity distribution per movement pattern and player were obtained from those data. Speed boundaries between movement patterns were obtained empirically by taking the intersections of the speed distributions of neighbouring patterns.

There were large inter-individual differences within these borders, for example, Player 1's transition from jogging to cruising/sprinting occurred at 3.95 $m.s^{-1}$whereas player 20's transition is only at 5.23 $m.s^{-1}$. The reasons for these findings may have been that players have individual styles of moving which emerge over a long period and are dependent on anthropometrical configurations and physiological characteristics that cannot be defined yet. This means that the conventional method of assigning one speed threshold for all the players was not supported by the results of the current study. In addition, a recent study of Abt and Lovell (2009) showed that movement speed thresholds in soccer matches do not correspond very closely to individual physiological measurements of physical capacities of the players.

Looking at the evidence from this sample, the conventional method of assigning movement patterns should not be considered a valid procedure. Speed analyses may be more economic, objective and reliable than observational methods, but their validity to assign correct movement patterns is questionable and the method needs to be reconsidered.

Also of concern, number and distance of certain intensities are often taken as measures of the load soccer players are exposed to during the match, from which inferences for physical preparation are drawn (Carling *et al*., 2005; Reilly, 2007). In order to know precisely the energy consumption of the players, much more information than just moving speed is needed, for example, moving with and without the ball makes a difference (Reilly and Ball, 1984) as well as the age of the players (Pereira Da Silva *et al*., 2007). Moreover there are many more than four or five different movement patterns and all have different energy demands (Carling *et al*., 2005; Reilly, 2007), for example, running forward or backward at the same speed should makes a big difference in energy consumption. Finally, information about what is semantically going on in the game are needed because, in many cases, two players can be facing each other in a one-on-one dribbling situation in which both are physically highly loaded but might not have high moving velocities.

Consequently a valid procedure to estimate the physical load of soccer players in a match has to consider movement pattern, movement speed and tactical situations. It must be validated on an individual basis taking individual physiological reactions into account. The widespread procedure of activity profiles based on general moving speed intervals has been shown in this study not to be representative of the players' actual activity.

This study only used data from a single match. To improve the validity and reliability established in this study a larger sample could be used. Moreover looking at differences in speed thresholds at the beginning of the match compared to the end of the match, the strength of speed thresholds vary for a single player in different matches should be considered and researched.

7. References

Abt, G. & Lovell, R. (2009). The use of individualized speed and intensity thresholds for determining the distance run at high-intensity in professional soccer. **Journal of Sports Sciences**, 27,893-898.

Bangsbo, J., Norregaard, L. & Thorso, F. (1991). Activity profile of professional soccer. **Canadian Journal of Sports Science**, 16, 110-116.

Bloomfield, J., Polman, R. & O´Donoghue, P. (2004). The 'Bloomfield Movement Classification': Motion Analysis of Individual Players in Dynamic Movement Sports, **International Journal of Performance Analysis in Sport**, 4, 20-31.

Beetz, M., Bandouch, J., Gedikli, S., Hoyningen-Huene v., N., Kirchlechner, B. & Maldonado, A. (2006). Camera-based Observation of Football Games for Analysing Multi-agent Activities, Proceedings of the fifth international joint conference on autonomous agents and multiagent systems, 42-49.

Beetz M., von Hoyningen-Huene, N., Kirchlechner, B., Gedikli, S., Siles, F., Durus, M. & Lames, M. (2009). ASPOGAMO: Automated Sports Games Analysis Models. **International Journal for Computer Science in Sport**, 8 (1), 4-21.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P. & Krustrup, P. (2009). High-intensity running in english FA premier league soccer matches. **Journal of Sports Sciences**, 27 (2), 159-168.

Carling, C. Williams, A. M. & Reilly, T. (2005). **The Handbook of Soccer Match Analysis**. London: Routledge.

Clark, P. (2010). Intermittent high intensity activity in English FA Premier League soccer. **International Journal of Performance Analysis in Sport**, 10 (2), 139-151.

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N. & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. **International Journal of Sports Medicine**, 28, 222-227.

Gwet, K. (2002). Kappa Statistic is not satisfactory for Assessing the Extent of Agreement between Raters. **Statistical Methods for Inter-Rater Reliability Assessment**, 1, 1-6

Hughes, M. & Franks, I. (Eds.). (2004). **Notational Analysis of Sport (2nd edition)**. London: Routledge.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M. & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. **International Journal of Sports Medicine**, 27, 483-492.

Lames, M. (1994). **Systematische Spielbeobachtung**. Münster: Philippka.

Mohr, M., Krustrup, P. & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. **Journal of Sports Sciences**, 21, 519-528.

Pereira Da Silva, N. Kirkendall, D.T. & Leite De Barros Neto, T. (2007). Movement patterns in elite Brazilian youth soccer. **Journal of Sports Medicine and Physical Fitness**, 47 (3), 270-5.

Rampinini, E., Bishop, D. Marcora, S. M., Ferrari Bravo, D., Sassi, R. & Impellizzeri, F. M. (2007). Validity of simple field tests as indicators of match-related

physical performance in top-level professional soccer players. **International Journal of Sports Medicine**, 28, 228-235.
Reilly, T. (2007). **Science of Training: Soccer**. London: Routledge.
Reilly, T. & Ball, D. (1984). The net physiological cost of dribbling a soccer ball. **Research Quarterly for Exercise and Sport**, 55, 267-271.
Van Gool, D., Van Gerven, D. & Boutmans, J. (1988). The physiological load imposed on soccer players during real match-play. In T. Reilly, A. Lees, K. Davids & W. J. Murphy (Eds.), **Science and Football** (pp. 51-59). London: Spon.