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Time Motion Analysis of Men's Professional Beach Volleyball

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TIME MOTION ANALYSIS OF MEN'S PROFESSIONAL BEACH VOLLEYBALL

by

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ABSTRACT

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Identifying work-to-rest ratios and rate of high-intensity movements provides a better insight into the physiological demands of sports, but no such analysis has been done in beach volleyball. Videotape footage, obtained from the Association of Volleyball Professionals (AVP), consisted of 12 healthy male professional volleyball players from three different AVP final matches during the 2008 season. Rally durations and high intensity movements (HIMs) were recorded. Total work and total match time means were identified, 13.7 minutes and 74.8 minutes, respectively. Only 17% of the total time the ball was actually in play. Overall mean rally time and rest times were also identified, $M = 6.7$ seconds and $M = 32.8$ seconds, respectively. The frequency HIMs was 0.8 per minute, with each player performing approximately 33.5 HIMs per set. T-test indicate no significant difference between winning and losing teams ($p = 0.73$). Further analysis on women and amateur-level players is warranted.

PREFACE

This thesis was written in article format for submission to the Journal of Strength and Conditioning Research following defense. The content and organization of this thesis represent and fulfill the requirements for submission to this journal.

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INTRODUCTION

Time Motion Analysis (TMA) has been described as the quantification of movement patterns involved in sports situations; providing speeds, durations, and distances of various locomotor patterns during the course of a game (4). TMA has been used in various sports for evaluating either athletes or referees, and for analyzing the temporal characteristics of performance so that individualized sport-specific conditioning programs may be developed (2). As such, TMA may increase the specificity of strength and conditioning programs by providing insight into the energy system and the specific movement patterns used throughout the course of a game (4). As cited by Mayhew et al. (11), Brodie proposed that TMA could help determine the contributions of the energy supply systems to soccer referees by estimating different match play activities; therefore, making suggestions for the prescription of specific training programs.

Another sport that might benefit from this type of information is beach volleyball. Volleyball is a power-dominated sport, requiring rapid and repeated applications of high force (14). These explosive efforts are characterized by short bouts of high-intensity effort intermingled with brief rest periods (13). Beach volleyball offers specific challenges to an athlete. Sand is a compliant surface that challenges a player's total body stability and ability to use the triple extension mechanism of ankle plantar flexion, knee extension and hip extension to propel the body efficiently (14). Also, rally scoring has lead to significant changes in the physiological demands of the sport (5, 12). The change from side-out scoring to the current rally scoring format has necessitated additional third sets at times, thereby increasing the number of rallies (5). Therefore, the physical demands of the sport are often greater today than in the past. Additionally, a beach volleyball team consists of only two players another reason for the increased physical demands of each individual in the game.

Most TMA studies in volleyball have focused on a single skill or gross movement patterns (12) in the indoor game; many of which were performed before several rule changes (1999) including service scoring to rally-point scoring (13). A few have focused on the change of intensity rather than gross movement patterns. Since no study to date has utilized TMA in professional beach volleyball, the current study used it to identify the work-to-rest ratios and rate of high-intensity movements therein. This novel investigative approach provides us with a better insight into the demands of this game, thereby enabling us to develop more appropriate strength and conditioning programs formulated for these athletes.

METHOD

Subjects

Videotape footage was obtained from the Association of Volleyball Professionals (AVP) and is considered public domain as it was filmed for television production purposes. Thus, informed consent is unnecessary. The video recordings consisted of 12 healthy male professional volleyball players (Age: 33 ± 3.2 years old; Height: 195.0 ± 7.1 cm; professional beach volleyball experience: 11.3 ± 2.5 seasons) from three different AVP final matches during the 2008 season was analyzed. The three matches that were analyzed are from the 2008 tour in Atlanta, GA, Belmar, NJ, and Hermosa Beach, CA. For consistency, the same investigator (CMW) performed all observations of high-intensity movement (HIM) and evaluated time of play for each point rally and the subjects. All matches used current FIVB best of 3-sets, rally scoring up to 21, and win-by-two points protocol. The final match in Atlanta went a full three sets, while the matches at Belmar and Hermosa Beach only required the initial two sets to determine the winner. However, the Hermosa Beach match played extra points in the second set in order for the winner to gain a two-point margin of victory.

Procedure

This investigation used a novel approach for data collection since the videotape footage was originally designed for television viewing purposes following the course of the ball. It should be noted however, that much of the court was visible at most times and that we believe all movements are accounted for in the video. Video used in this analysis was acquired for television replay via Digibeta-camera at 60 Hz. The video-camera was positioned above the officials table at mid-court. The footage was copied from the camera to a compact disk to be reviewed post match; slow motion viewing was performed to evaluate movements by each player on the court.

Measurement

During the match, HIMs were counted by type per player, per rally. High-intensity movements were operationally defined and categorized into actions such as: block attempt, attack attempt, jump serve, rundown or dig requiring more than two steps, or any other high-intensity movement identified by the investigator. These movements are understood to require a high rate of work to perform. Frequency of high-intensity movements was calculated over the course of each set and match.

Another measure of TMA was the time of play per point rally. Time was monitored on the screen by hours, minutes and seconds from the video camera counter. Work time was counted in seconds from the moment the serving player put the ball in play (i.e. ball accelerates forward) until the moment the referee indicated the ball was dead or out of play. Rest time was calculated from the moment the ball was dead until the next serving player put the ball into play. Rest time included time between points, and time-outs, but not the time between games in the match. All measures were reported in International System of Units (SI).

Data Analysis

Data were analyzed using SPSS 16.0 software. Data are presented as mean±SD, including descriptive data on overall work-to-rest ratios, as well as frequency of high intensity movements per player. T-tests were performed to examine differences between the winning and losing teams for all work-to-rest ratios in each match. An alpha level of significance was set at $p < .05$.

RESULTS

The player demographics are given in Table 1. A combined 261 points were scored between the three matches; however only 247 rallies were used in the analysis. The matches had a mean of 13.7 minutes total work and a mean total time of 74.8 minutes. Therefore, 17% of the total time the ball was actually in play. Work and rest ratios are given in Table 2. The results of the TMA revealed an overall mean rally time of 6.7 seconds and an overall mean rest time of 32.8 seconds. The longest rally between all three sets lasted approximately 25 seconds with the shortest rally being a serving ace lasting approximately 1 second. Rest time between rallies ranged from a television timeout at 219 seconds (3 minutes: 39 seconds) to as short as 14 seconds.

The unit of analysis is the volleyball game, or set, within the match. The overall mean frequency of all HIMs was 0.8 per minute. Throughout the match, each player performed approximately 33.5 HIM per set. Overall mean frequency of HIM per player by set is given in Table 3. The t-test for HIM between the winning and losing teams has a p value was $p= 0.73$, therefore the difference between winning and losing teams for HIM per minute is not statistically significant. A repeat analysis of the third game from the Atlanta match showed high reliability and precision of all independent variables with and ICC >.7 and Coefficient of Variation <10%.

DISCUSSION

This novel investigation had two primary purposes. The first was to identify the work-to-rest ratios and the second was to identify the frequency of high-intensity movements in men's professional beach volleyball using TMA. Ultimately, this investigation provides us a better understanding of the demands of this game and potentially improves the specificity of strength conditioning programs of these athletes. Work-to-rest ratio is somewhat subjective depending on the definition of rest (4). Since locomotion in the sand is more difficult than locomotion on a sturdy playing surface like indoor volleyball, even low intensity movements require an additional output of work, suggesting work may actually be underestimated if only using work-to-rest ratios. Using the operational definition of rest in this study as the absence of HIM, the high-intensity effort technique is a reasonable way to calculate the physiological demands.

Considering any motion, including high and low-intensity movements, is more difficult to perform in the sand. This includes walking on sand, which requires 2.1 to 2.7 times more energy expenditure than does walking on a hard surface such an indoor wooden court (9). The increase in energy expenditure as compared to indoor volleyball is due to two reasons, mechanical work on the sand and the decrease in efficiency of propulsion by the muscles and tendons (9). Regarding HIMs, significant biomechanical differences exist concerning jumping in the sand versus on a rigid surface like an indoor volleyball court. Vertical jump high is significantly smaller on sand; in addition maximal force and power output are lower in sand as compared to a rigid surface (6). However, significant correlations have been shown between sand and rigid surface vertical jump performances, suggesting that vertical jumping abilities exist in general quality (1). Therefore, training in the sand may be beneficial to vertical jump performances in indoor volleyball due to training the individual's body to overcome ground reaction forces.

Minor differences in work-to-rest ratio and rate of high-intensity movements were expected between sets and matches. This investigation revealed a mean rally time of 6.7 seconds and an overall mean rest time of 32.8 seconds suggesting reliance on ATP-PCr. The rare longer rallies, such as the 25-second rally in the first set in Atlanta, GA, could utilize the glycolyic system, but it is unlikely that there is continuous activity by each player. Rest time between rallies ranging from a television timeout at 219 seconds (3 minutes: 39 seconds) to as short as 14 seconds would appear to allow ample recovery time.

In relationship to other sports requiring high-intensity movements, beach volleyball places considerable demands on the neuromuscular system based on the work-to-rest ratios when the ball is in play (13). Given the range of work and rest periods, the overall work-to-rest ratio for beach volleyball is roughly 1:6. This is comparable to professional soccer, men's field hockey and women's hockey with work-to-rest ratios of 1:7 (11), 1:5.7 (8), and 1:5.7 (10), respectively, as shown in Table 4.

In relationship to Australian Football League umpires, beach volleyball players spent slightly more time in play, 6.7 seconds compared to 2.8 seconds, and had slightly longer recovery periods with a work-to-rest ratio of 1:4.5

compared to 1:6 (3). Conversely, in relationship to wheelchair racquetball, beach volleyball players in our study spent slightly less time in play as compared with 9.1 seconds for A-level players and 7.99 seconds for B-level players and W:R of 1:1.5 and 1:2.3 respectively, also shown in Table 5 (7). Since an individual volleyball player may not be highly active for the time that the ball is in play, one may be able to better describe beach volleyball using the HIM per unit time

Obtaining data on which to base a conditioning program was the goal of this investigation, thus the HIM method is more applicable. Limited research has been done concerning indoor volleyball; even less has examined beach volleyball, research which only began recently (12, 13). Beach volleyball players appear to utilize the phosphagen energy system to a large degree with only 0.8 HIM per minute based on our data. Other sports requiring short bouts of high-intensity activity such as indoor volleyball, basketball, and American football may also benefit from similar analysis, as some players are not active for the entire time the ball is in play. Identifying ideal energy system training methods for these sports will not only improve competition performance but in reducing fatigue may in essence decrease the chances of injury.

A video recording error that occurred in the first set of the Hermosa Beach match resulted in the loss of the first 10 minutes of data, so data collection began at set score 8-6. Despite incomplete data on HIM for the Hermosa Beach, CA match we feel our sample size is adequate especially when concerning the rate of HIM. Due to the nature of the sport, many rallies and HIMs occur over the course of the game, and our data were collected using 12 different athletes in three different final matches. Continued investigation is necessary to provide us additional understanding of the demands of this game, and continue to improve specificity of strength and conditioning programs of these athletes. Addition of heart rate, weight loss, and caloric expenditure during a match may add to our body of knowledge since many beach volleyball matches are played in hot conditions. Additional data on other levels of beach volleyball and women is also suggested.

PRACTICAL APPLICATIONS

Time motion analysis reveals a reliance on multiple energy system to fulfill the high-intensity demands of beach volleyball player, but likely little aerobic contribution. The rate of high intensity activities is relatively low, suggesting the maximal power may be more important to success than high-intensity endurance. Training programs should be designed to fit the ranges of the game settings during the pre-season to improve specific performances. These findings were based on professional male volleyball players, thus coaches and strength and conditioning professionals should adjust training programs according to the level of the player's ability.

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Appendix A

TABLES

Table 1. Player Demographics

	Mean	SD
Age	32.8	3.2
Experience	11.3	2.5
Height	195.0	7.1

Table 2. Overall work/rest times by set, seconds

	Set	Work (sec)	SD	Rest (sec)	SD	Ratio
Atlanta	1	5.7	4.1	32.0	32.3	1:5
	2	5.9	3.6	32.7	33.3	1:5
	3	5.6	3.0	29.9	13.6	1:5
Belmar	1	7.4	4.0	29.7	28.6	1:4
	2	6.8	3.7	31	32.7	1:4.5
Hermosa Beach	1	7.7	4.4	38	43.0	1:5
	2	7.8	3.9	35.8	25.8	1:4.5

Table 3. Mean frequency of HIM per player per set

	Set	Mean	SD
Atlanta	1	15.0	9.4
	2	32.5	3.9
	3	20	9.8
	Match	22.5	9.8
Belmar	1	48	17.7
	2	34.5	9.3
	Match	41.3	14.9
Hermosa Beach	1	23.3	5.0
	2	50.5	2.4
	Match	36.9	15.0

Table 4. Comparison of work-to rest ratio

	Sport	Work-to-Rest Ratio
Current Investigation	Men's Professional Beach Volleyball	1:6
Mayhew et al.	Professional Soccer	1:7
Johnston et al.	Men's Field Hockey	1:5.7
Lothian et al.	Women's Hockey	1:5.7

Table 5. Comparison of mean work time and work-to-rest ratio

	Sport	Mean Work Time (seconds)	Work-to-Rest Ratio
Current Investigation	Men's Professional Beach Volleyball	6.7	1:6
Coutts et al.	Australian Football Umpires	2.8	1:4.5
Higgs et al.	Wheelchair Racquetball	9.1 7.99	1:1.5 1:2.3

APPENDIX B

EXTENDED LITERATURE REVIEW

Definition of Time Motion Analysis (TMA)

Time motion analysis has been described as the quantification of movement patterns involved in sports situations providing speeds, durations, and distances of various locomotor patterns during the course of a game (6). TMA is a technique for analyzing the temporal characteristics of a sporting performance as a preliminary to developing a sport-specific conditioning program (3). It is thought that TMA may increase the specificity of strength and conditioning programs by providing insight into the physiological demands of a sport by quantifying activity patterns of an athlete (9).

Performing TMA typically utilizes one of two methods; video-based analysis and analysis utilizing Global Positioning Systems (GPS). The most commonly used method is video-based (6). Video-based analysis typically use one to seven cameras placed at different locations around the playing surface. For best viewing, Dobson et al. recommended cameras be positioned at the halfway point at an elevation of 3 to 20 meters, and 5 to 30 meters from the sideline for field sports (6). Court games have used a similar number of cameras but have positioned them at an elevation of 1.5 to 5 meters and 2 to10 meters from the sideline (6). When filming player movements, two types of camera placements or approaches have typically been used.

The most common methodological approach to TMA uses one to four cameras with each camera focuses on a single player for the duration of a quarter, half, or entire game (7). This type of filming enables observers to have a closer view of the relevant player at all times. It increases the precision of their measure, allowing an increased ability to code each movement pattern accurately. Some researchers using this approach have proposed filming a small area of field/court around the athlete, as opposed to a full zoom of the athlete, to provide a frame of reference for gauging movement activities (4, 5, 18). A 5-m radius around the player was recommended as the optimal balance between maximizing the proportion of the field of view taken up by the athlete and being able to have an adequately sized frame of reference (5).

The second approach involves cameras viewing the entire playing surface, usually for field sports, with overlapping views allowing all players to be seen. This approach to TMA typically involves the use of two cameras that are positioned in line with the halfway mark; each camera is focused on one-half of the field of play with a small overlap of field of view between the two cameras (22). This allows the movements of all players to be seen at all times during the course of the game and provides the opportunity for all players to be analyzed. An advantage to this approach is that it is less time consuming; however, it is more difficult to identify and code movements.

Another method of TMA utilizes GPS, which allows accurate tracking of a change in horizontal position in real time by calculating the displacement between the signal or satellite and the receiver placed on the athlete being tracked. There are some distinct disadvantages with this as compared to video-based TMA. For instance GPS cannot currently be used indoors or within heavily developed urban areas since large buildings interfere with satellite signals (6). Another disadvantage is the need to wear a small receiver on the upper back of the participant, supported by shoulder straps (6). This limits GPS usage to sports only involving a low level of physical contact, but for such sports the analysis process is more automated. Since currently GPS is limited to horizontal displacement, it is unable to evaluate vertical displacement that occurs in volleyball; therefore, GPS is not the ideal method for TMA of volleyball.

History of Volleyball

Volleyball was invented by William Morgan in 1895. As the Director of Physical Education at the Young Men's Christian Association in Holyoke, Massachusetts, he had the opportunity to establish, develop, and direct a program of exercises and sport classes for the men. Originally named Mintonette, Morgan decided to blend elements of basketball, baseball, tennis, and handball to create a game for his classes of businessmen (1). He wanted something competitive such as basketball to attract the young men, but less violent and with less physical contact for older gentlemen. Thus, he borrowed the net from tennis and raised it to six feet six inches above the floor. During a demonstration, someone remarked that players seemed to "volley" the ball back and forth over the net. The nickname seemed a more descriptive name for the new sport; consequently, from then on the new game was called volleyball.

Volleyball is a power-dominated sport, requiring rapid and repeated application of force to performing skills (21). These explosive efforts, which are characterized by short bouts of high-intensity exercises, are intermingled with brief rest periods (20). Beach volleyball offers specific challenges to an athlete. Sand is a compliant surface which challenges a player's total body stability and ability to use the triple extension mechanism of ankle plantar flexion, knee extension and hip extension to propel the body efficiently (21).

Beach volleyball started in the United States in the 1920's. It was originally played for fun and recreation. The first beach doubles games were played in 1930 in Santa Monica, CA (15). Initially, players were not allowed to jump serve or block and the match was seemingly endless side-outs. A team could only score after their own serve; as a result the single game match could last for hours with ball possession changes. Now, due to rally scoring, sets are much shorter, thus, allowing for the current FIVB rules: best of 3-sets, rally scoring up to 21, win by two points protocol (10). This has led to significant changes in the physiological demands of the sport (11, 19). Research indicates after the change in side-out scoring to the current rally scoring format, the necessity for third sets increased, thus the number of rallies increased (11). Therefore the physical demands of the sport increased.

Six-person indoor volleyball was introduced as an Olympic sport in 1964. Thirty-two years later, beach volleyball was introduced as an Olympic sport in the 1996 Atlanta Olympics. Twenty-four men's teams from 19 nations and 18 women's teams from 13 nations participated. The USA men's teams finished 1st

and 2nd. Due to its popularity, many organizations have been formed to promote and govern the sport such as The United States Volleyball Association (USVBA, now USA Volleyball), Association of Volleyball Professionals (AVP), California Beach Volleyball Association (CBVA), and international organization Federation Internationale De Volley-Ball (FiVB) (15).

Comparison of Indoor and Beach volleyball

There are similarities and differences between indoor volleyball and beach volleyball. Many rules and regulations are similar; the men's net is placed at 2.43m while the women's net is slightly lower at 2.24m for both beach and indoor volleyball (10). However there are a few key differences as noted in the following statements by the FiVB (9).

1. Indoor volleyball requires six people on each side of the court; whereas beach has two players on each side.
2. The surfaces of the courts are different; indoor volleyball requires a flat, smooth, non-slip surface whereas beach volleyball can be played on either sand or grass.
3. Indoor volleyball separates the court into 9 m by 9 m halves. Beach volleyball has switched to 8 m by 8 m halves.

4. The beach ball has a slightly larger circumference of 66-68cm as compared to the indoor ball with a circumference of 65-67cm. The ball also feels as though it weighs more and has less air pressure. The beach ball has a pressure of 0.175 to 0.225 kg/cm^2 versus an indoor ball inside pressure of 0.3 to 0.325 kg/cm^2.
5. Indoor and beach volleyball rules allow only 3–contacts per side, but in beach volleyball the block counts as a touch. With two players per team on the court at one time in beach volleyball, an individual player has more potential touches per rally.
6. Scoring is also different between the two games. FiVB Indoor volleyball plays 5-sets with rally scoring to 25 points while FiVB Beach plays 3-sets with rally scoring to 21 points both indoor volleyball and Beach volleyball require a win by two points (10).
7. Other game rules that differ involve players passing under the net, serve rotation, and skills such as tipping.

Previous TMA Investigations

Many studies have been performed using TMA. Sports studied include rugby (5, 7, 9), racquetball (12), field hockey (13, 22), ice hockey (16), basketball (23), Gaelic football (14), Australian football (4), soccer (8, 17, 18), dressage horses (3), beach soccer (2) and more recently, tennis and volleyball (19, 20). Most studies reviewed for this investigation focused on using video-based analysis for TMA; however, all investigators did not use the same data collection approach. TMA investigations used one of two approaches to collect data. Where specified, most studies used single-subject tracking; however, a few utilized stationary camera data collection. Along with the variation in data collection approaches, three variables dominated the investigations reviewed: movement patterns, work-rate, and a combination of movement patterns and work-rate.

Movement patterns have been investigated and variables analyzed using both data single subject tracking collection approaches. For single-subject tracking, zoom percentages vary between studies; nevertheless, focus is placed on the individual's movement rather than the entire playing surface (4, 7, 18). Two studies utilized multiple cameras to track selected players' movement patterns during a rugby match (7, 9). Docherty et al. used four cameras to track centres and props on both rugby teams, believing they should show the most considerable differences in time-motion profiles (7). Players were followed for alternating 5 minute time periods throughout the game and player movements were coded into six categories (7). Frequency of movements and time spend in each movement was recorded. This study determined rugby players spend 15 percent of match play in intense activities, 6 percent is related to running while 9 percent activities such as tackling, pushing, and competing for the ball (7). On the other hand, Duthie et al. determined there are different movement pattern demands between rugby positions, indicating a high degree of specificity for player positions (9). The study by Mohr (18) also used single-subject tracking;

however, many cameras were used to assessing movement patterns in soccer players. Mohr et al. concluded top-class soccer players performed more high-intensity running and sprinting than moderate players (18). Also, Mohr et al. determined defenders covered less total distance and performed less high-intensity running than other positions, while midfielders cover a greater total distance but sprinted less than forwards and defenders (18). These findings support previous research on specificity of training by differences in positional demands.

Another study examined gross movement patterns in elite female beach volleyball players (19). However, instead of single-subject tracking, the researchers used a two-stationary video camera approach, both calibrated and synchronized. This investigation focused on the amount and time spent on offensive movement patterns and defensive movement patterns (19). Multiple stationary cameras have also been used to study movement patterns of elite field hockey players (22). The study concluded walking, standing, and jogging accounted for 95 percent of activities during the duration of the match leaving the remaining 5 percent of player game time to high-intensity activities such as striding and sprinting (22). Another study used an unspecified video-based method for tracking data on elite men's volleyball players focusing on movement patterns of specific volleyball positions (20). The investigation determined different physical demands are placed on Middle blockers in comparison to other positions studied; also suggesting training loads should be monitored to prevent overuse injuries (20).

Work-rate was only investigated using the single-subject tracking approach, where a single camera was used to perform single-subject tracking for assessing work-to-rest ratios for professional soccer players (17). This investigation analyzed two players for seven minutes at a time while categorizing movements and tracking time spent in each activity (17). This methodology is based on the TMA investigation by Brodie in 1981 as cited by Mayhew et al. (17). The authors believed TMA could help determine the contributions of the energy supply systems to soccer referees by estimating different match play activities; therefore, making suggestions for the prescription of specific training programs (17). Using the data collection approach as described by Docherty et al. above (7) for assessing movement patterns, the work-rate of elite rugby players was also analyzed (5, 7, 9). Along with previous investigations, forwards were found to perform 2.5 times as much more high-intensity work than backs with shorter rest periods in between bouts of work (5). The work rates of the different positions require emphasis on separate energy systems. This investigation supports previous data that individualized energy system training by position is needed in rugby (5). Similarly, a single-subject, single-camera approach was used to assess elite soccer players for work-rate profiles (8). Drust et al. analyzed 90 minutes of videotape footage for 23 professional soccer players categorizing movements according to intensity of the action. The work-rate of the player was determined to be dependent on the competition and positional role of the individual (8). Yet another single subject tracking approach was used when assessing work-to-rest ratios of Gaelic football (14). In this investigation, two stationary cameras overlooking separate halves of the field were used. One camera was positioned over a player position while the other camera was positioned on the other half of the pitch so that two player positions could be observed simultaneously (14). Work-rate analysis determined Gaelic football players spend most of the game performing sub-maximal movements which rely heavily on the aerobic energy system (14). One investigation used an unspecified approach with multiple cameras to assess work-to-rest ratios of women's hockey (16). A mean work-to-rest ratio of 1:5.7 seconds with a range of 1:3.8 to 1:7.9 seconds was established (16). Another study also used this approach to data collection, where a single camera was used in addition to heart rate monitors, while comparing work-to-rest ratios of field hockey players during practice and competition (13). This investigation was the few TMA studies that used additional equipment to monitor athletes. The investigators video-recorded continuously and analyzed one training session and one competitive match. Results concluded there was a statistically significant difference in work-to-rest ratios indicating competitions are more physically demanding than practice sessions (13).

Finally, the combination of, movement patterns and work-rate was investigated. One study used the video-based method applying the single-subject tracking approach explained earlier by Docherty et al. (7); for assessing movement patterns and work rates of Australian football umpires (4). Coutts et al. used a single camera with zoom to follow one of the three umpires during the entire match. The study found that the three umpire system has reduced physical demands as compared to the older two-umpire system with an average work-to-rest ratio of approximately 1.4-1.5 (4). Another study also used a single camera to assess the movement patterns and work-rates of dressage horses. A single camera was placed behind markers either midway down the long side of the arena or in the corner of the arena (3). An investigation that used a single stationary camera approach examined the work-to-rest ratio of wheelchair racquetball athletes (12). A single camera placed behind the court recorded continuous data throughout the matches. Higgs et al. observed more proficient athletes had longer rallies while lesser proficient athletes took longer rest periods. Proficient athletes had an exercises-to-pause ratio of 1:1.5 while the less proficient level had a ratio of 1:2.3 (12). However, as compared to able-bodied court games, work-rates were significantly higher. None the less, both wheelchair racquetball and able-bodied racquetball athlete's E:P ratios indicate a dominance of aerobic energy system usage. A data summery of collection methods for these studies is shown in Table 6.

Table 6. Comparison of Investigational Methodology

	Sport	Approach	Cameras	Variables Analyzed	Other
Castellano (2)	Beach soccer	GPS	N/A	Movement Patterns/ Work Rate	GPS device and HR monitor
Clayton (3)	Dressage Horses	Single-Subject Tracking	1	Movement Patterns/ Work Rate	
Coutts (4)	AFL Umpires	Single-Subject Tracking	1	Movement Patterns/ Work Rate	
Deutsch (5)	Rugby	Single-Subject Tracking	Multiple	Work Rates	
Docherty (7)	Rugby	Single-Subject Tracking	4	Movement Patterns	2 cameras followed 2 positions per team
Drust (8)	Soccer	Single-Subject Tracking	1	Work Rate	Repeated for all subjects
Duthie (9)	Rugby	*Unspecified	Multiple	Movement Patterns	
Higgs (12)	Wheelchair Racquetball	Stationary Camera	1	Movement Patterns/ Work Rate	
Johnston (13)	Field Hockey	Single-Subject Tracking	1	Work Rate	Repeated for all subjects Additional HR monitor used
Keane (14)	Gaelic Football	Single-Subject Tracking	2	Work Rate	1 camera on each half of field
Lothian (16)	Women's Hockey	*Unspecified	Multiple	Work Rate	Rated intensity of activities
Mayhew (17)	Soccer	Single-Subject Tracking	1	Work Rate	Alternated player footage every 7 min
Mohr (18)	Soccer	Single-Subject Tracking	Multiple	Movement Patterns	Zoom for close up viewing
Pérez-Turpin (19)	Women's Beach Volleyball	Stationary Camera	2	Movement Patterns	
Sheppard (20)	Men's Volleyball	*Unspecified	*Unspecifie d	Movement Patterns	
Spencer (22)	Field Hockey	Stationary Camera	2	Movement Patterns	

*Some investigators did not specify how data collection was performed.

While the data collection methods for these studies vary widely, it is clear that TMA can be a useful tool for describing the physical demands of a sport and tailoring a strength and conditioning program to improve performance. More research is needed to add to the body of literature concerning volleyball at different levels of competition.

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