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UNIVERSITY OF ALBERTA

TIME MOTION ANALYSIS AND PHYSIOLOGICAL PROFILE OF ELITE LEVEL WHEELCHAIR BASKETBALL PLAYERS

BY

LARA A. BLOXHAM

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitles, "Time Motion Analysis and Physiological Profile of Elite Level Wheelchair Basketball Players" submitted by Lara A. Bloxham in partial fulfillment of the requirements for the degree of Master of Science.

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Dr. Y. Bhambhani

Date: Oct. 6, 1995

DEDICATION

This thesis is dedicated to John and Sheila Bloxham, who always knew I could do it and who have provided unconditional support for anything that I wanted to do or tried. It is also dedicated to my best friend and coach, Darrell, who quietly kept pushing me to finish. Finally this thesis is dedicated to the players who helped, without them this project would never have happened.

ABSTRACT

Wheelchair basketball (WCBB) has unique physiological demands. During the summer of 1994, the Gold Cup - World Wheelchair Basketball Championships were held in Edmonton. This provided an opportunity to evaluate the physiological profiles of elite level WCBB players and to determine the heart rate response and time spent performing various activities during a WCBB game of these same players. Six male athletes with disabilities, members of the Canadian National WCBB team ranked third in the world, volunteered to participate in the study. Each player was video taped during a game situation in order to determine the time spent during various types of activity. In addition, heart rate was recorded every 5 seconds to indicate the relative intensity of the activity.

Physiological measurements (mean +/- sd) included peak oxygen consumption (peak VO_2) measured while their wheelchair was mounted on a set of rollers (mean 2.595 l/min +/- 0.524), maximum anaerobic power performed on an arm crank ergometer (mean 486.39 watts +/- 68.13), shoulder flexion and extension isokinetic strength at 60 and 180 degrees per second respectively (mean 66.3 Nm +/- 10.5, 95.3 Nm +/- 13.3, 54.3 Nm +/- 11.5, 85.3 Nm +/- 6.1), anthropometric measures (body weight mean 69.1 kg +/- 8.6; sum of four skinfolds 38.5 mm +/- 9.8) and shoulder flexion and extension flexibility (mean 170.3 deg +/-13.1, 53.7 deg +/- 6.3 respectively).

The WCBB games (consisting of two twenty minute halves) were split into seven different categories in order to encompass the variety of activities involved. The categories were: sprint, sprint with ball, shooting, shooting with movement, gliding, struggling and resting. Preliminary time motion results indicate that the majority of the time spent on the court was either sprinting (383.77 sec +/- 229.55), gliding (1010.85 sec +/- 500.34) or struggling (783.00 sec +/- 354.18). These results indicate that the game of WCBB stresses primarily the anaerobic metabolic systems based on the sprinting, struggling time motion results and anaerobic power scores shown by the experienced and seasoned players. However, a strong aerobic base was required to promote quick recovery and sustain play for the entire 40 minutes of play as shown through the gliding and peak VO_2 scores.

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Chapter One

Time Motion Analysis and Physiological Profile of Elite Level Wheelchair Basketball Players

Introduction

Numerous studies have determined physiological measurements of athletes with disabilities (Coutts, 1988; Coutts, 1990; Veeger et al, 1991;), including wheelchair basketball players (Hutzler, 1993; Ibusuki et al, 1990; Kobayashi et al, 1990; Rotstein et al, 1994). Although the dynamics of wheelchair basketball have been studied (Coutts, 1992), a time motion analysis of the game of wheelchair basketball has not been conducted. Research using time motion analysis techniques is limited (Alexander et al, 1987; Catterall et al, 1993; Docherty et al, 1988; Higgs, 1990; Reilly and Thomas, 1976; Wilkins et al, 1991) and to date, only one published time motion analysis study investigated wheelchair sport (Higgs 1990). Time motion analysis combined with physiological data on the player can be an important tool to describe the time spent performing various activities within a sport, the physiological demands of that sport and allow development of effective training programs for athletes.

Purpose

The purpose of this study was to: (1) determine the heart rate response and time spent, by elite wheelchair basketball players performing various activities during a wheelchair basketball game and (2) describe their physiological profiles using standardized test procedures.

The time motion analysis consisted of video taping wheelchair basketball players during the entire length of a game situation in order to determine time spent during activity and the activity type. For analysis, seven activity types were indicated and defined; sprint, sprint with ball, shooting, shooting with movement, gliding, struggling and resting. Heart rate was recorded every 5 seconds to indicate intensity of activity. Each physiological profile consisted of measurements of the following: Peak oxygen consumption, maximum anaerobic power, four anthropometric measures, shoulder isokinetic strength and shoulder flexibility.

Hypothesis

The hypothesis was that (1) the majority of the wheelchair basketball game time would be spent performing anaerobic activities, and (2) aerobic fitness would be necessary for quick recovery and to help prevent fatigue during the length of a game and would be evident in high peak oxygen consumption.

The following research questions were investigated:

1. What percentage of time was spent performing each type of activity?
2. What was the frequency of each activity?
3. What was the total time spent performing each activity?
4. What was the mean time spent performing each activity and the standard deviation of the mean time?
5. What were the highest and lowest duration's of time spent performing each activity?
6. Of the time spent playing, what was the frequency of each activity, total time spent performing each activity and the percentage of time spent performing each activity?
7. What physiological stress was imposed on each individual during each activity type, based on heart rate response during the game?
8. What were the physiological profiles of elite level WCBB players including peak VO_2, anaerobic power, shoulder flexion and extension isokinetic strength and power, shoulder flexibility and anthropometric measures

Limitations

1. Due to the varying nature of each athlete's disability, results of this investigation were applicable to athletes of similar disability and IWBF classification levels.
2. Testing was conducted on members of the Canadian National Wheelchair Basketball contingent.

3. Time motion analysis was conducted during practice games between Canada and other national teams.

Delimitations

1. Subjects were male wheelchair basketball players with IWBF classification levels between 1.0 and 4.5. They were members of a contingent vying for a spot on the Canadian National Wheelchair Basketball team who represented Canada at the 1994 Gold Cup competition held in Edmonton, Alberta, from July 21 to 30, 1994.

Definitions

Anaerobic Power:

The ability of the body to perform short, explosive bouts of activity without the use of oxygen.

Anthropometry:

The measurement of the size and proportions of the human body.

Flexibility:

The range of motion about a joint.

Isokinetic Strength:

Force produced at a constant velocity through a range of motion.

Paraplegia:

A spinal cord injury occurring at or below the first thoracic vertebrae, causing involvement of the lower extremities.

Peak Oxygen Consumption (peak VO_2):

The peak rate at which oxygen can be consumed per minute; the power of the aerobic or oxygen system.

Poliomyelitis:

An acute viral infection causing inflammation of the gray matter of the spinal cord, followed by paralysis and atrophy of various muscle groups.

Spinal Cord Injury:

Traumatic insult to the spinal cord resulting in alterations of the normal motor, sensory and autonomic function.

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Chapter Two

Time Motion Analysis and Physiological Profile of Elite Level Wheelchair Basketball Players

Introduction

With the growing recognition and popularity of disability sport, in addition to the increased inclusion of athletes with a disability into national and international sporting events such as the Canada Winter Games and the Commonwealth Games, comes a need for a greater understanding of the sports and advancement in athlete training techniques. Recently there have been an increased number of investigations that have determined the physiological measurements of individuals with a disability (Bhambhani et al., 1992; Bhambhani et al., 1993; Bhambhani et al., 1994; Burkett et al., 1990; Davis, 1993; Glasser et al., 1980; Hjeltnes, 1977; Hopman et al., 1992; Hopman et al., 1993; Hopman, 1994; Janssen, et al., 1993; Jehl et al., 1990; Rasche et al., 1993; Sawka et al., 1980; Van Der Woude et al., 1988; Van Loan et al., 1987), athletes with a disability (Coutts, 1988; Coutts, 1990; Veeger et al., 1991; Wicks et al., 1983) and wheelchair basketball (WCBB) players (Hutzler, 1993; Rotstein et al., 1994). Although the dynamics of WCBB had been studied (Coutts, 1992) a time motion analysis of the various activities involved has not been investigated.

Research using time motion analysis techniques is limited (Alexander et al., 1987; Ali and Farrally, 1991; Catterall et al., 1993; Clayton, 1993; Docherty et al., 1988; Higgs, 1990; Wilkins et al., 1991) and to date, only one investigation had studied sport for persons with a disability which described the work rates of wheelchair racquetball players (Higgs, 1990). The game of WCBB is similar to that of its stand-up counterpart in terms of rules and game play. However, each player is assigned a point value dependent on his/her physical disability and international rules state that there must be a certain number of points on the playing floor at one time (IWBA manual). Playing time and position may be determined by point classification. Using time motion analysis techniques, the intensity, duration and frequency of different activity types can be determined, and when used with synchronized heart rate information and physiological data, a better understanding of each point classification, position and the overall game can be attained. A greater understanding of the physiological requirements of the game as a result of a time motion analysis, in addition to personal physiological information about an athlete, will aid in the development and prescription of an effective training program.

The purpose of this investigation was to perform a time motion analysis of the variety of activities involved in WCBB and compare those to heart rate information recorded on elite wheelchair basketball players during a game situation. Secondly, a physiological profile data assessment of peak VO_2, anaerobic power, shoulder isokinetic strength, shoulder flexibility and anthropometric measures, was completed to gain a better understanding of the physiological characteristics of wheelchair basketball players.

METHODS

Subjects and Experimental Design

Although seventeen players were videotaped, only six male volunteers who were currently members, or vying for a spot on the Canadian National Wheelchair Basketball team, signed informed consent and agreed to participate in both the time motion analysis and physiological testing. The subjects ranged in age from 21 to 34, International Wheelchair Basketball Federation classification between 1.0 and 4.5 and had acquired a physical disability since birth. See table 2-1-a for a complete description of subject characteristics and physiological profiles. A descriptive experimental design was chosen to study the relationship between activity type, time spent performing each activity and intensity (Smith and Glass, 1987). This design was chosen in order to allow description of the data in addition to providing more information about the physiological demands of wheelchair basketball. This project was approved by the Faculty of Physical Education and Recreation Ethics Committee for the use of human subjects in research.

Testing Procedures

Time Motion Analysis

The time motion analysis required filming each individual subject during the entire length of a wheelchair basketball game. Rather than possibly interrupting players normal play by wearing a HR monitor and being video taped during the Gold Cup Wheelchair Basketball tournament, all video recording was done prior to the tournament during high caliber international exhibition play. The video cameras were situated in the stands, located above the indoor, hard wood playing surface. Seventeen players, playing a variety of different positions, were filmed over the course of 5 days of recording. A computer software program specially designed for analysis was used to code the game activity, while viewing video playback on a television screen. To minimize the number of activity types, seven different categories were chosen through observation and personal reference by two independent observers and were based on intensity and physiological demands. Due to the small number of subjects, analysis by playing position was not possible.

Sprint:

Quick movement across the playing surface, including offensive and defensive directions.

Sprint with the ball:

Quick movement across the playing surface in the offensive direction while handling the ball

Shooting:

Shooting the ball at the basket with little or no movement from inside or outside the key, including foul shots.

Shooting with movement:

Quick movement towards the basket followed by a shot or a lay-up.

Gliding:

Any movement across the playing surface with light or no arm strokes.

Struggling:

Defensive or offensive struggling for position (with or with out the ball), or movement into or out of the wheelchair during game play.

Resting:

Resting/sitting with no movement or struggling on or off of the game surface.

During analysis, resting was split into resting (floor) and resting (bench), in order to provide a better description of how playing time was spent.

The videos were coded for the entire length of the game (two, twenty minute halves). During the intermission, the cameras where left on but analysis was not continued. All video analyses were completed by the same individual. Intra-rater reliability was obtained by re-analyzing one randomly selected, entire selected, entire game segment of the same individual. To test inter-rater reliability, one randomly selected entire game segment was analyzed by another individual, familiar with the sport of wheelchair basketball.

Heart Rate

Heart rate was recorded during the game time using a PE 3000 Sport Tester (Polar Electro Ltd.). Prior to the first half, each player was fitted with an electrode chest strap and the watch transmitter was attached to the back or underneath their wheelchair. Each monitor was started just prior to game time. Heart rate was then recorded and saved to memory every 5 seconds during the first half of the game. During the intermission each watch transmitter was changed to guarantee heart rate was recorded for the entire game length. Heart rate was then recorded for the second half as previously stated. Upon completion, the watch monitors were interfaced with a computer and all heart rate data was downloaded into the PE 3000 Sport Tester Software Program.

Laboratory Tests

To gain physiological information and data regarding intensity in relation to heart rate, various maximal performance tests were completed. All subjects were asked to refrain from any formal physical activity one day prior to the testing.

The subjects reported to the laboratory and were given an orientation and both written and verbal explanation about the tests. Anthropometric measures were completed first, including body weight and 4 skinfold measurements using Harpenden calipers (biceps, triceps, chest and subscapular). Due to the varying nature of physical disabilities and the prevalence of paraplegia in wheelchair basketball players, anthropometric measurements were taken above the level of the sixth thoracic vertebra. Skinfolds were determined using the Canadian Standard Test of Fitness protocol (Government of Canada, 1986). A maximum of three measures were taken from each site and an average of the closest two was used.

Isokinetic shoulder strength of the dominant arm, was tested using a Cybex isokinetic dynamometer (Ronkonkoma, NY). Calibration procedures where as described in the Cybex procedures manual (Cybex Division of Lumex, Inc. Ronkonkoma, NY.). Peak torque was determined from the highest point on the torque vs. angular curve for shoulder extension as during each contraction at angular velocities of 60 and 180 degrees per second. Subjects were strapped in the supine position on the bench in order to aid balance and isolate the shoulder rotator muscle. The axis of the dynamometer was visually aligned with the center of the shoulder joint and the length of the lever was adjusted to fit securely into the hand of the subject. Each subject was allowed a submaximal warm-up at each angular velocity and then performed 4 maximal contractions at 180 degrees and 3 maximal contractions at 60 degrees per second. Although speeds should be randomly assigned, 180 degrees per second was performed first due to the quicker recovery rate than 60 degrees per second. Combined peak torque (Nm) was determined from the highest of each set of contractions at both speeds.

Anaerobic power was determined using a modified Windgate 30 second cycle protocol at maximal effort on an arm crank ergometer (Bar-Or et al., 1974). Resistance was determined as .047 kg per kg of body weight (MacDougall et al, 1991), and remained constant during the 30 second period. Peak and mean power output were determined using a specially designed computer software package. Subjects were required to complete a short warm-up (28 seconds) at zero resistance followed by 2 seconds of wheeling with minimal resistance. At this time the investigator indicated the need for the subjects to increase their revolutions per minute to a maximal speed at which time the investigator increased the resistance to the predetermined level. The subject continued as hard as possible for the entire 30 second period. Following the test, the subject was encouraged to remain on the arm crank ergometer to continue an active recovery and was monitored closely during this period until recovered.

A continuous, wheelchair ergometry test was used to determine peak oxygen consumption (peak VO_2) during an incremental velocity test to fatigue. Subjects were required to warm-up for two to five minutes at a set velocity (2 km/h). Following the warm-up, velocity was increased by two kilometers an hour every two minutes until exhaustion. Heart rate was recorded continuously throughout the test. The following criteria for achieving peak VO_2 was used (Fox et al., 1988):

1. oxygen consumption peak and/or plateau (a change of less than 100 ml per minute with an increase in exercise);
2. respiratory exchange ratio exceeded 1.1;
3. volitional exhaustion occurred.

All subjects met this criteria except for plateau of oxygen consumption.

Ventilatory threshold one (VT_1) was determined by detecting the power output at which the V_E/VO_2 reached a minimum, while ventilatory threshold two (VT_2) was determined by detecting the power output at which the V_E/VCO_2 ratio reached a minimum (Bhambhani and Singh, 1985). The two thresholds were identified by this investigator and verified for reliability by one other independent evaluator.

Results

The physiological profile data of subjects 1 through 6 are represented in table 2-1-a. All subjects completed the peak VO_2 test and ventilatory threshold two (VT_2) determination (mean 2.595 l/min +/- 0.524; 1.81 l/min +/- 0.26 respectively); maximum anaerobic power, available for two subjects only (mean 486.39 watts +/- 68.13); shoulder flexion and extension isokinetic strength and power (mean 66.3 Nm +/- 10.5, 95.3 Nm +/- 13.3, 54.3 Nm +/- 11.5, 85.3 Nm +/- 6.1); anthropometric measures (body weight mean 69.1 kg +/- 8.6; sum of skinfolds 38.5 mm +/- 9.8) and shoulder flexion and extension flexibility (mean 170.3 deg +/-13.1, 53.7 deg +/- 6.3 respectfully).

A summary of the time motion analysis data are provided in table 2-2. Individual data summaries are given in appendix B.

Table 2-1-a Physiological Profile Data

FITNESS PARAMETERS	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
FIBA CLASSIFICATION	1	4.5	2.5	4	3.5	2
*DISABILITY	SCI	AMP	SCI	AMP	AMP	SCI
AGE	34	24	22	33	22	21
BODY WEIGHT - KG	64.7	72.3	63.7	56.8	72.9	84
**S.O.S. (FOUR SITES) - MM	47.1	35.8	26.5	27.7	39.9	53.7
SHOULDER EXTENSION (60 DEG/SEC) - NM	81	61	n/a	57	n/a	n/a
SHOULDER FLEXION (60 DEG/SEC) - NM	114	84	n/a	88	n/a	n/a
SHOULDER EXTENSION (180 DEG/SEC) - NM	53	69	n/a	41	n/a	n/a
SHOULDER FLEXION (180 DEG/SEC) - NM	81	94	n/a	81	n/a	n/a
SHOULDER FLEXIBILITY (EXTENSION)- DEG	56	60	n/a	45	n/a	n/a
SHOULDER FLEXIBILITY (FLEXION)- DEG	169	187	n/a	155	n/a	n/a
ANAEROBIC POWER (PEAK) - WATTS	n/a	n/a	418.26	n/a	554.51	n/a
ANAEROBIC POWER (MEAN) - WATTS	n/a	n/a	261.41	n/a	412.19	n/a
VO2 PEAK (ABSOLUTE)- L/MIN	2.12	3.14	1.73	2.55	2.91	3.12
VO2 PEAK (RELATIVE) - ML/KG/MIN	32.77	43.43	27.16	44.89	39.92	37.14
HEART RATE (PEAK) - BPM	185	189	186	168	173	185
VENTILATORY THRESHOLD TWO - L/MIN	1.61	2.08	1.43	1.69	1.9	2.15
PERCENTAGE VT - %	76	66	83	66	66	69

* Disability: SCI - Spinal Cord Injury

AMP - Amputee, single or double

** S.O.S.: Sum of skinfolds (bicep, tricep, subscapular, chest)

Table 2-1-b Physiological Profile Data Means and Standard Deviations

Fitness Parameters	Mean	Standard Deviation
FIBA Classification	2.9	1.2
Age	26	5.4
Body Weight - kg	69.1	8.6
S.O.S (Four Sites) - mm	38.5	9.8
Shoulder Extension (60deg/sec) - Nm	66.3	10.5
Shoulder Flexion (60deg/sec) - Nm	95.3	13.3
Shoulder Extension (180deg/sec) - Nm	54.3	11.5
Shoulder Flexion (180deg/sec) - Nm	85.3	6.1
Shoulder Flexibility (ext) - deg	53.7	6.3
Shoulder Flexibility (flex) - deg	170.3	13.1
Anaerobic Power (peak) - Watts	486.3	68.1
Anaerobic Power (mean) - Watts	336.8	75.4
VO_2 Peak (absolute) - l/min	2.60	0.52
VO_2 Peak (relative) - ml/kg/min	37.55	6.12
Heart Rate Peak - bpm	181	7.7
VO_2 at VT_2 - l/min	1.81	0.26
Percentage VT_2 - %	71	6.4

Table 2-2 Time Motion Data Summary; Total Time Spent VS Percentage of Time Spent (Totals do not equal to 100%, the remaining percentage was spent as intermission between game halves).

	Struggling	Sprint w Ball	Sprint	Shoot w Mvm't	Resting Bench	Resting Floor	Gliding
Total Time (sec)	783.00 +/- 354.18	27.18 +/- 15.05	383.77 +/- 229.55	12.87 +/- 10.45	1544.37 +/- 801.22	532.11 +/- 583.99	1010.85 +/- 500.34
Time (%)	14.855 +/- 4.89	.530 +/- .257	7.18 +/- 3.05	.256 +/- .228	32.86 +/- 16.31	10.057 +/- 9.672	19.200 +/- 6.993

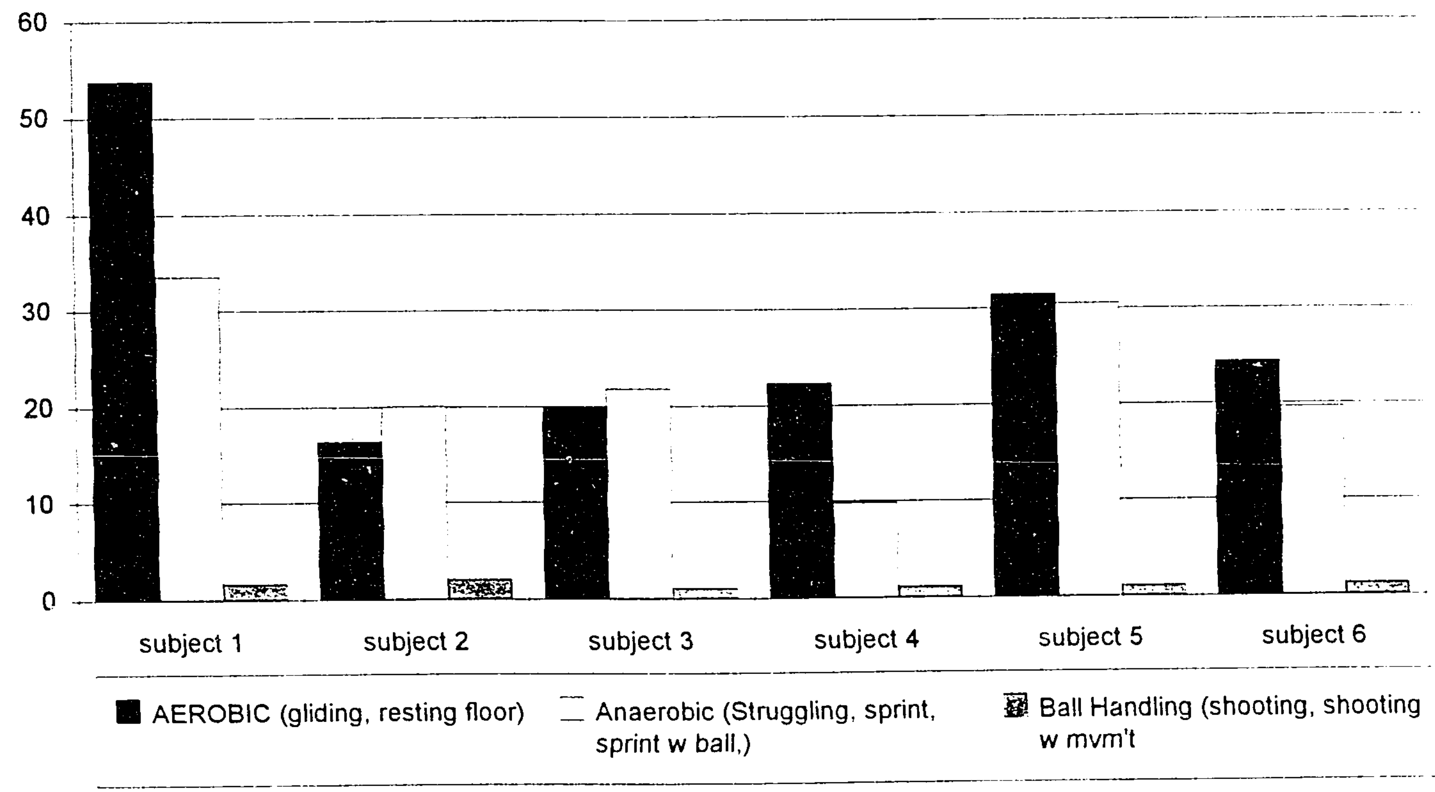
Heart rate data for subjects 1 through 5 are given in Appendix C. Due to technical difficulties, HR data for subject 6 was not available for analysis. Table 2-3 provides specific information regarding VT_2, HR peak and comparison of the first and second halves.

Table 2-3 Heart Rate Responses During a Wheelchair Basketball Game in Relation to VT_2 and HR peak

NAME	HR @ VT.	HR MAX	% @ or above VT. 1st Half	% @ or above VT. 2nd Half	% @ or above MAX 1st Half	% @ or above MAX 2nd Half
Subject 1	167 b/min	185 b/min	23 %	7%	2%	3%
Subject 2	157 b/min	189 b/min	21%	20%	1%	0%
Subject 3	169 b/min	186 b/min	33%	11%	13%	0%
Subject 4	167 b/min	171 b/min	7%	1%	6%	0%
Subject 5	140 b/min	173 b/min	34%	50%	18%	11%

Note: HR peak as indicated during peak VO2 testing.

Figure 2-1 Percentage of Time Spent Performing Different Activity Types: Aerobic Recovery, Anaerobic, Ball Handling



Discussion

The two main purposes of this investigation were to determine the HR response and time spent performing various activity types during a WCBB game and to describe the physiological profiles of elite level wheelchair basketball players. Time motion data was collected by video taping each individual player during the entire length of a WCBB game while HR was recorded simultaneously by telemetry. Although not complete for all players, peak oxygen consumption, maximum anaerobic power, anthropometric measures, shoulder isokinetic strength and shoulder flexibility was collected in a laboratory setting. It was hypothesized that the majority of the time spent during a WCBB game would be anaerobic in nature and that the physiological profiles of the players would fit those demands. The present findings suggest that except in two cases (subject 2 and 3) actual time spent performing anaerobic activities did not account for the majority of time during a WCBB game. However, in relation to total amount of playing time, anaerobic activities do account for a high percentage of time. The players physiological characteristics support these findings, showing high peak VO_2, and VT's as compared with other investigations (Bhambhani et al., 1995 in press; Lin et al., 1993; Rotstein et al, 1994).

The physiological data, particularly peak VO_2 and HR peak, are comparable to those found by other investigators (Coutts, 1990; Glasser et al, 1980; Hopman et al; 1992; Rasche et al, 1993; Veeger et al, 1991). A good comparison can be made between the subjects of this investigation and those from an investigation performed by Rotstein and colleagues (1994). Their study looked at physiological parameters of WCBB athletes of comparable playing level and international classification. Although HR peak values were comparable for the most part, peak VO_2 values (for their comparable players) were on average 11.97 ml/kg/min less than that of this investigation; 25.60 ml/kg/min for Rotstein et al.(1994), as compared to 37.57 ml/kg/min for this study. In addition, VT data for the present investigation was also higher than that of Rotstein's when expressed as a percentage of HR peak (72% as compared to 58%). One explanation for this may be the method used to determine peak aerobic power, Rostein et al (1994) used a graded exercise test at a constant speed by placing a wheelchair on a motor driven treadmill while the present study used a roller system with a constant grade and incremental velocity. The differences in protocols could have made a difference in the final aerobic power readings.

Coutts (1988) examined the HR responses of different wheelchair sports during practice and game situations using similar data collection techniques. His results showed a practice mean of 122 bpm (s.d.=12.3) and game situation mean of 148 bpm (s.d.=6.4) with a range of 91-202 bpm. The results of this investigation showed the game average to be 128 bpm with a range of 64 to 227 bpm. It should be noted that 227 bpm is out of normal physiological range and this reading may be a result of technical interference of the HR monitors. In addition, Coutts looked at the percentage of time spent at greater than 140 bpm as a point of significant training effect in paraplegics (Knutsson et al, 1973). However, a comparison cannot be made because all of the participants in this study were not paraplegics. Table 2.3 shows the percentage of time that each player spent at or above their VT HR, which might be a better comparison to Coutts' work. Perhaps an explanation for the difference in mean game H.R.'s were the sample of subjects used. There were no description of the participants in the Coutts' study (1988), therefore, it was impossible to make any comparison of the physiological or WCBB classification characteristics.

As shown in Figure 2-1, subjects two and three spent more time performing anaerobic activities than aerobic activities. A comparison of the percentage of time spent at or above their ventilatory threshold (Table 2.3) seems to support this. Subject two spent 20.5% of his time at or above VT and subject three spent an average of 22% of the time at or above VT. Of the remaining three subjects with available HR data, subject five spent almost an equal amount of time performing aerobic and anaerobic activities as supported by VT data (on average 42% of his playing time was spent at or above VT). It was also interesting to note that all players only spent between 1.39% and 2.15% performing ball handling activities, no matter how much time spent on the playing floor.

The categories chosen for this investigation were designed to separate the skills of WCBB down into different activities based on personal observation, knowledge of the game, intensity and physiological demand. Other investigators have also separated games or activities into categories based on intensity (Catterall et al., 1993; Docherty et al., 1988; Wilkins et al., 1991). Two of these investigations studied the physiological demands of officiating soccer (Catterall et al., 1993) and hockey (Wilkins et al., 1991), while the other examined the game of rugby (Docherty et al., 1988). All of these investigations were dealing with non-disabled, lower body activities and were able to separate the activities into standing, walking, reverse walking, jogging, running, sprinting and non-running activities. In the case of Wilkins et al (1991), standing, gliding, slow skating, fast skating, sprinting, and utility were utilized. Although a time motion analysis of wheelchair racquet ball has been done (Higgs, 1990), the games are quite different and similar categories could not be used. The categories chosen in the present study were similar to those used in stand up sport: gliding, sprinting, resting, struggling, shooting, shooting with movement and sprinting with ball. These categories seemed to account for most of the movement and activity on the floor as determined by the total time spent performing each activity. When defining the categories, two independent observers with knowledge and personal experience with WCBB, and wheelchair wheeling in general, agreed on the categories and definitions. However, because each player was followed for the entire length of the game it was necessary to break the category of resting into two components: resting on the bench and resting on the floor. Only one player played the entire length of the game while the other five spent some time sitting on the bench. The category of shooting and shooting with movement could have been combined based on the small amount of time spent performing either of these activities. Sprinting with the ball was another activity that was not performed very often. It seemed that the game of WCBB was mainly a passing game and ball handling for the most part (with this group of players) was less important.

It would have been useful to separate the play time of each player into the first and second halves to determine any change in activity type. This was because the one player who played the entire game showed a substantial decrease in HR response from first to second half of the game (see Appendix C, Figure C-1). As pointed out by Wilkins and colleagues (1991), psychological stress may contribute to an increased HR response of the players during a game situation. This is contrary to the present findings because usually as a game progresses the psychological stress increases. However, in this case as the game progressed, the players HR decreased instead of increased. The decrease in HR may be a result of fatigue or a game or coaching strategy. Of the six players whose data was analyzed, all but one seems to be a good indicator of their playing style. Subject four, however, did not play as much as he would normally play. This may be one explanation for the difference in aerobic recovery time as compared to anaerobic activities (Figure 2-1). To gain a better understanding of each players style, time motion analysis should be done on more than one game in order to gain more reliable information about each player. It is also important to note that not all players were videotaped during the same game and intensity may vary from game to game.

It seems that the game of WCBB was both aerobic and anaerobic in nature. When examining the time motion data in relation to the HR responses of the players (Tables 2-2, 2-3, Appendix C, Figures C-1 through to C-6). There were numerous stops and starts, bouts of sprinting and struggling, and periods of rest. The HR data, including the percentage of time spent at or above VT, seems to support the time motion information. A remaining question is whether the player's physiological profiles in the present study are indicative of the fitness requirements to excel in WCBB? In comparison with the study by Rotstein et al. (1994) the athletes in this investigation were substantially more fit than those of comparable personal characteristics. Peak oxygen consumption measures were similar to or higher than those found by other investigators (Coutts, 1990; Hutzler, 1993; Rotstein et al., 1994; Wicks et al., 1983; Veeger et al., 1991) and anaerobic power of two of the participants in this investigation were higher than those of similar or greater international classification (Hutzler, 1993). In addition, the VT data collected in the present investigation support the high aerobic fitness levels of the participants. Because no data was found in the literature measuring isokinetic shoulder strength (flexion and extension) in wheelchair athletes, there was nothing to compare these results to. Based on the aerobic and anaerobic profiles of the subjects in this investigation it would seem that their physiological profiles fit those required of a WCBB player.

Time motion analysis is a useful tool to indicate the physiological demands of an activity. Once this information is learned it can then be applied in a number of areas; in preparation for a game, what to look for in players (screening) and in designing training programs. When preparing for a game, tournament or even for a year of play, it is useful for a coach or player to know what the majority of the game time is spent doing, pin pointing individual players strengths and weaknesses and building a game plan for that. Although both players and coaches must be careful when using physiological data as screening for team selection, the information can be used for identifying the strengths and weaknesses of players and to aid in proper design of training programs. For example, a player has a high peak VO_2, is very proficient technically but experiences localized muscular fatigue quite quickly in comparison to other players. This player may want to spend time increasing arm and shoulder muscular strength and endurance during the off season and perform sprint and interval training to increase his/her speed and fatigue resistance.

In summary, the game of WCBB seems to be characterized by a need for high aerobic fitness based on the length of each game (usually an hour to an hour and a half), the time spent in aerobic activities, and the peak VO_2 scores of the players in this study. A high anaerobic power is also required based on the amount of time spent sprinting and struggling and the high aerobic and ventilatory threshold scores. As previously mentioned, the athlete that played the entire length of the game showed a substantial change in HR response between the first and second halves. This may have indicated a change in playing style or fatigue but this was not evident with the present data. Application of these results to training prescription suggest that training programs for WCBB players should include a strong aerobic component in combination with sprint and interval training in order to increase each players' anaerobic power and capacity. Further investigation is needed to determine if there is a difference between playing style and physiological demands of different international classification levels and disabilities.

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APPENDIX A

REVIEW OF LITERATURE

1.0 Introduction

The purpose of this review was to investigate the current research pertinent to the area of time motion analysis and physiological response to upper body exercise. More specifically, the focus was the time motion analysis and physiological response of wheelchair basketball.

2.0 Wheelchair Basketball

2.10 A Brief History

The origin of wheelchair basketball was often a topic of dispute. Labanowhich (1975) stated that a game similar to what we know today as wheelchair basketball was played in England as early as 1945, however, the exact location was unknown. One of the most common theories stated that modern day wheelchair basketball was started post World War II by various Veterans Administration Hospitals within the United States (Owen, 1982). The first documented activity occurred in both New England and California, around the same time in 1946. The first competitive game of wheelchair basketball was held in 1947 between two disabled teams from California. With an increase in popularity of the game, the (USA) National Wheelchair Basketball Association was formed in 1949 and held the first national competition that same year in Illinois (Labanowhich, 1975; Owen, 1982). These events not only marked the beginning of disabled sport but gave wheelchair basketball the distinguished honor of being the oldest wheelchair sport in the world (Kelly and Friedin, eds. 1989).

The first international wheelchair basketball competition was held in England during the 1956 Stoke Mandeville Games which were the first games of their kind for disabled athletes (Kelly and Frieden, eds., 1989; Labanowhich, 1975; Owen, 1982). Since it's humble beginnings, wheelchair basketball has grown to be the most popular team sport for individuals with a disability in the world. In Canada many able-bodied individuals participate as well, due to the games growing popularity (Kelly and Eriedin, eds., 1989). These players are still not permitted to play internationally.

Originally, wheelchair basketball was played only by spinal cord injured individuals or more specifically, paraplegics, and they were the only people permitted to play internationally. Today the game is opened to many disabled individuals including those with poliomyelitis, amputations, spina bifida, cerebral palsy and all others who qualify for wheelchair sport. It should be noted, however, that due to the loss of function of much of the upper extremities quadriplegics do not normally participate in wheelchair basketball at a highly competitive level.

2.11 Physiological Demands

Many investigators have studied the sport of wheelchair basketball and wheelchair basketball players (Calmels et al, 1992; Coutts, 1988; Coutts, 1990; Hutzler, 1993; Ibusuki et al, 1990; Kobayashi et al, 1990; Rot[illegible] et al, 1994). The heterogeneity of wheelchair basketball teams was often a problem when forming conclusions (Rotsein et al, 1994). Heart rate response (HR) of wheelchair basketball players was documented as beinq the highest when compared to other wheelchair and disabled sports including track and field, swimming, racquetball and tennis (Coutts, 1988; Veeger et al, 1991). Average HR responses during game situations ranged from 148 to 186 beats per minute. Coutts (1988) found that average heart rates during practice were 26 beats per minute lower than during the game situation (122 bpm compared to 148 bpm during a game). In this same investigation, HR responses ranged form 76 bpm to 202 bpm, indicating the individual differences of players. Maximal oxygen consumption scores for wheelchair basketball players (37.9 ml/kg/min) was second only to track and field (44.9 ml/kg/min) and swimming (39.0 ml/kg/min) (Veeger et al, 1991).

Recently, Rotstein and colleagues (1994) determined the aerobic power and anaerobic threshold of elite level Israeli wheelchair basketball players. Peak VO_2 scores ranged from 17.0 to 38.7 ml/kg/min, with an average of 24.1 ml/kg/min. Mean percent heart rate reserve for these subjects was 57% and ranged from 41% to 81.2%, at a corresponding 4 mM blood lactate level. Due to the lack of available data regarding anaerobic threshold for wheelchair athletes, no norms were available for comparison. These investigators concluded that the fitness level of these subjects was average and were similar to recreational athletes instead of elite, national or international level athletes.

3.0 Time Motion Analysis Research

Many different forms of time motion analyses have been used to estimate the time spent in different activities and how they relate to the energy requirements of that particular activity (Docherty et al, 1988). This can be done by categorizing each activity involved in performance using intensity, frequency, mean time and the total time spent engaged in a particular activity or group of activities (Wilkins et al, 1991). One of the first investigations using time motion analysis research was conducted by Reilly and Thomas (1976) who determined the time and work rate of different positions of professional soccer players. More recently, research in this area has been done with rhythmic gymnastics (Alexander et al, 1987), rugby players (Docherty et al, 1988), wheelchair racquetball (Higgs, 1990), amateur ice hockey officials (Wilkins et al, 1991) and soccer referees (Catteral et al, 1993).

Docherty and colleagues (1988) selected rugby props and centres (27 players) and video taped each player for approximately 50% of the total game time. A specially designed computer software program was used to record the different activities of the players. Each activity was coded into one of six categories: standing, walking, jogging, running, sprinting and non-running intense activity. The analysis indicated that the players spent 85% of their time engaged in low intensity activity (standing or walking), 6% running and the remaining 9% engaged in other activities such as tackling, pushing and competing for the ball. From their research, Docherty et al (1988) concluded that props and centres performed high intensity, short duration work and should focus training on developing the creatine phosphate energy system.

Wilkins et al (1991), filmed four amateur hockey referees and seven linesmen during the entire length of four University level hockey games. The activities of each were split into six categories based on intensity: standing, gliding, slow skating, fast skating, sprinting and utility (restraining players). Each official's heart rate was recorded using a PE 3000 Sport Tester (Polar Electro Ltd.) every 5 seconds and saved to memory. Each subject completed a fitness test consisting of height, weight, adiposity and maximal oxygen consumption (VO_2 max) measurements. The results indicated that the referees exceeded the linesmen in the total time spent in relatively low-intensity activity (96.4% to 94.4% respectively). In addition, all officials maintained a heart rate of 70% of their maximal values at least 70% of the time. The researchers concluded that aerobic fitness is important for ice hockey officials in order to reduce fatigue during a game situation

Another investigation using officials, this time in association football, was conducted by Catterall et al (1993). Fourteen experienced class 1 referees were video taped during the 90 minutes of play. The total distance covered by each official was determined by calculated their stride length during several types of activity including walking, jogging, sprinting, and reverse running. Heart rate was used to indicate the stress imposed on the cardiovascular system of each referee and was then used to show the relationship between work rate and heart rate. The results of this investigation indicated that the majority of the distance covered by the referees was done using submaximal intensity exercise. However, because of the wide variety of activities and the time spent during each game, high aerobic as well as anaerobic capacities were required to meet the demands of high level soccer refereeing (Catterall et al., 1993).

Although most time motion studies have been conducted with team oriented events, some research has been done with individual sports. An investigation by Alexander and colleagues (1987) determined heart rate response and time motion analysis of rhythmic sportive gymnastics. The researchers recorded heart rate every 5 seconds of four highly skilled rhythmic gymnasts (using portable recording units). Prior to the filming, each athlete was required to complete a battery of fitness tests: percent body fat, VO_2 max, anaerobic alactic power, lactic power, flexibility and various strength measures. Heart rate was monitored during the performance of 5 different routines: rope, hoop, clubs, ball and ribbon. Blood lactate values were estimated for each subject following the performance of the first routine. The average time for each performance was between 80 and 90 seconds. The total distance and average velocity was determined using the video analysis, as well as classification of the different types of movements performed. Through the comparison of exercise intensities of each apparatus, the results suggested that the rope routine was the most physically demanding for the athletes. It was also concluded that anaerobic power was important in many of the skills required for rhythmic sportive gymnastics, based on the high velocities of the activity and subsequent heart rates.

One area that has not attracted much interest in time motion analysis research has been in sport for the physically disabled. However, Higgs (1990) conducted a preliminary time motion analysis for the sport of wheelchair racquetball. The game was played on the same court and with the same equipment used by their able-bodied counterparts and seemed to be well suited for individuals with a disability. The purpose of this investigation was to gain information regarding the rallies, distances, speeds, wheelchair turns, and the choice of strokes used by the players rather than the intensity which was the focus of the other studies mentioned. Because the selection of matches analyzed was not random, the results were not viewed as being representative of typical or average levels of play (Higgs, 1990). The time of each rally was recorded as was the time at the start of each pause between each rally. In addition, the number and magnitude of changes in direction and position on the court, were determined using video analysis. From this information, the total distance covered and the player's speed of movement was calculated. The ratio between exercise to pause between exercise was greater for wheelchair racquetball than for able-bodied racquetball. This information, along with the time motion analysis, led Higgs (1990) to conclude that the predominant energy system used during this sport was aerobic. It should be noted that Higgs (1990) did not use heart rate response or blood lactate measures to determine which physiological system was stressed predominately. Due to the intermittent nature of the game of racquetball, it would be safe to assume that there is a strong anaerobic component involved.

Although it has not been used extensively, time motion analysis was a useful tool for determining work rates of, and physiological strains caused by, different forms of exercise. When used in conjunction with physiological profiles and heart rate determinants during activity, time motion analysis provided useful information that could be used to develop effective training programs.

4.0 Physiological Response to Upperbody Exercise

Since the 1970's there has been an increased number of investigations covering the physiological response of persons to upperbody exercise (Bar-Or and Zwiren, 1975; Burkett et al, 1990; Connor, 1991; Coutts, 1990; Cowell et al, 1986; Davis et al, 1991; Franklin, 1989; Gass and Camp, 1984; Glasser et al, 1980; Hjeltnes, 1977; Hooker and Wells; 1989; Hooker et al, 1993; Hopman et al, 1993; Hutzler, 1993; Jehl et al, 1991; Sawka et al, 1980; Sawka, 1986; Van Loan et al, 1987; Veeger et al, 1991; Rotstein et al, 1994) For many, including some individuals with physical disabilities, upperbody activity was their only available mode of exercise. People who experienced a physical disability, whether it be congenital or due to traumatic onset, were threatened with poor health because of the sedentary lifestyle that normally accompanied a physical disability. It was stated that "inactivity compounds the effects of disability" (Fentem, 1992). For example, a spinal cord injury below the first thoracic vertebra (also called paraplegia) has been associated with a decrease in motor functioning, atrophy of the muscle and bone and poor cardiovascular function below the level of injury (Cowell et al, 1986; Davis, 1992). Decrease in cardiovascular function, combined with a sedentary lifestyle, increase the risk of cardiovascular and other diseases such as adult onset diabetes and hypertension (Connor, 1991; Cowell et al, 1986; Pitetti, 1992; Shephard, 1991). There were also many possible complications that lead to a decreased life expectancy for the SCI individual (Staas et al, 1993). It is now known, however, that physical activity can prevent and reverse many of the factors that lead to disease and early death (Cowell et al, 1986; Fentem, 1992).

It is important to define what forms of activity are referred to with upper body exercise. Traditionally, exercise testing for persons with a lower body disability was performed using either a wheelchair on a treadmill or rollers, or an arm-crank ergometer (Sawka, 1986). Many studies have used both modes of exercise to elicit physiological responses (Burkett et al. 1990; Coutts, 1990; Cowell et al, 1986; Hjeltnes, 1977; Hopman et al, 1993; Hutzler, 1993; Jehl et al, 1991; Van Loan et al, 1987; Veeger et al, 1991; Rotstein et al, 1994). Arm-crank ergometry was known to produce a maximal heart rate (HR) response 10 beats per minute less than leg exercise, while wheelchair ergometry produced a HR response approximately 10 beats per minute less than that of arm-crank ergometry (Glasser et al, 1980). Wheelchair ergometry requires synchronous movement, while arm-crank ergometers tend to require asynchronous movement. Sawka and colleagues (1980) discovered that oxygen consumption (VO_2) and ventilation expired (V_E) both increased linearly due to increased power output during both forms of exercise. However, wheelchair ergometry produced higher VO_2 and V_E during the same situation than did arm-crank ergometry. These findings where supported by Gass and Camp (1983). Similarly, cardiac output, heart rate (HR), stroke volume (SV) and systolic blood pressure also increased with increased power output (Sawka et al, 1980). These same researchers believed that wheelchair ergometry was less efficient than arm-crank ergometry because Q, HR, SV and systolic blood pressure were higher for wheelchair ergometry. Therefore, wheelchair ergometry produced larger cardiovascular, metabolic and pulmonary stress (Connor, 1991; Gass and Camp, 1983; Glasser et al, 1980; Sawka et al, 1980).

4.10 Aerobic Exercise

Aerobic metabolism is characterized by the oxidation of carbohydrates, amino acids and triglycerides to water and carbon dioxide, in order to produce adenosine triphosphate (Thoden, 1991). In humans, the capacity to perform prolonged exercise is determined by the ability to utilize oxygen as the primary metabolic system. Oxygen uptake is said to be determined by two limiting factors; central and peripheral (Sutton, 1992). Cardiac output (Q) is determined by two factors, heart rate and stroke volume, or how well the heart and lungs work together to pump oxygenated blood to other parts of the body. Some believe that humans have a finite, maximal Q which does not change depending on the mode of exercise (Sutton, 1992). Peripheral limiting factors determine the ability of oxygenated blood to reach the muscle. It is determined by calculating the difference of the oxygen content of arterial and venous blood supply (Fox et al, 1988).

Increased metabolic requirements occur with the initiation of physical exercise (Sawka, 1986). At rest, oxygen uptake is similar between the trained and untrained. During activity, a trained individual's VO_2 max can be double that of the untrained. Maximal oxygen consumption, or cardiovascular fitness, has also been used as an indicator of heart disease. As already stated, individuals with physical disabilities are at an increased risk for heart disease due to their sedentary lifestyle. Research has suggested that most physically disabled individuals, particularly those with lower spinal cord injuries, respond in the same manner to exercise as able-bodied individuals (Cowell et al, 1986) Davis and colleagues (1991) found an increase in SV due to increased venous return and on average, a 21% increase in aerobic capacity of SCI men with 24 weeks of training. Hopman, Oeseburg and Binkhorst (1992) determined that during submaximal exercise a lower SV was compensated for by a higher HR, therefore, reaching similar Q to that of an able bodied control group at the same oxygen uptake levels.

Maximum oxygen consumption (VO_2 max) can be defined as the maximum amount of oxygen that can be taken in, per unit of time, and utilized by the body to continue activity until exhaustion (Thoden, 1991). It was commonly agreed in the literature that the maximal or peak aerobic power achieved during upper body exercise was approximately 30 to 35 percent lower than that achieved by lower body exercise (Connor, 1991; Wells and Hooker, 1990). This was due to the decreased muscle mass utilized during this form of exercise. As previously discussed, oxygen uptake was determined by two factors, central and peripheral (Sutton, 1992). During maximal upper body exercise there were many possible peripheral limiting factors to performance. For example, there was a reduced potential to generate muscular tension due to the smaller total muscle mass and smaller cross sectional area of the muscles being utilized. In addition, because of the smaller muscle mass and the difference in muscle fiber composition and motor unit recruitment patterns, there was a reduced oxidative capacity. Finally, there was a reduction in blood perfusion to skeletal muscle. This resulted from the smaller maximal vasodilatation due to the smaller total capillary cross sectional area and the intramuscular pressure exceeding that of the pressure caused by the transference of blood across the capillaries (Sawka, 1986).

Most exercise physiologists agree that during maximal exercise activity, such as running, when body weight is not supported by a device it should be thought of as a true maximal response to exercise. Activity with body weight supported, such as cycling, should be considered a peak exercise response. Upper body exercise, such as wheelchair ergometry or arm-crank ergometry, is weight supported, therefore, maximal oxygen consumption responses should be thought of as peak VO_2 instead of max VO_2 even though it has been referred to as maximal in the literature. The reliability and validity of VO_2 peak measures during upperbody exercise was studied by Bar-Or and Zwiren (1975). They discovered that maximal arm exercise elicited a VO_2 peak on average 63% of maximal leg exercise. They believed that individuals were aided by their trunk and leg muscles to differing degrees and that this was one reason why individuals with spinal cord injuries produced lower oxygen consumption measures compared to that of able bodied individuals (Sawka, 1986).

Many researchers have studied the maximal oxygen consumption of individuals performing upperbody exercise (Burkett et al, 1990; Coutts, 1990; Hopman et al, 1992; Hutzler, 1993; Van Loan et al, 1987; Veeger, 1991; Rotstein et al, 1994). As previously discussed, during submaximal exercise individuals with SCI reach higher HR response in order to compensate for a lower SV (Hopman et al, 1992). During maximal arm crank exercise, disabled subjects reported lower cardiac output values than able bodied subjects. Individuals with a physical disability reported a 67% increase in Q, mainly due to increased HR (Hjeltnes, 1977). Van Loan et al (1987), discovered that quadriplegic individuals had lower SV and HR measures while paraplegic subjects produced HR values equivalent to those of the able bodied individuals.

Evidence showed that peak VO_2 in the SCI individual was partially determined by the level and completeness of the injury (Bhambhani et al, 1991; Burkett et al, 1990; Van Loan et al, 1987). In general, the higher the level of injury the lower the peak VO_2. This may be due to a reduction in functional muscle mass available for use (Burkett et al, 1990; Van Loan et al, 1987; Wicks et al, 1983). In addition, impairment of sympathetic vasomotor regulation in SCI individuals has been documented as the primary cardiovascular limitation during exercise (Wells and Hooker, 1990). Following a SCI, vasoconstriction function below the level of lesion is lost, which resulted in decreased venous return and reduced ability to increase SV, also known as venous pooling. With training, individuals with physical disabilities increased their aerobic capacity (Cowell et al, 1986, Davis et al, 1991; Franklin, 1989; Hooker and Wells, 1989; Davis, 1993; Shephard, 1991). Evidence indicated that highly trained wheelchair athletes had 38% higher peak VO_2 measures and 32% higher SV than did sedentary disabled individuals (Davis, 1986). Although both groups of subjects experienced venous pooling below the level of injury, the trained individuals exhibited higher Q and lower arterial venous oxygen difference at the same HR and VO_2. The investigators concluded that a central adaptation had occurred due to training. Peak power output has also been shown to increase without an increase in peak VO_2 indicating an increased efficiency of oxygen delivery during exercise (Hooker and Wells, 1990).

4.11 Anaerobic Exercise

Anaerobic glycolysis involves the breakdown of muscle glycogen to lactic acid. This process does not directly utilize oxygen resulting in a high intensity but short duration supply of energy during exercise (Green, 1991). Due to the fatiguing nature of anaerobic exercise, tests that measure anaerobic power are usually short, lasting 20 to 30 seconds and tests of anaerobic capacity are measured between 60 and 90 seconds. Very little research has been conducted in the area of the anaerobic power and capacity of physically disabled individuals. Coutts and Stogryn (1987) determined the peak anaerobic power outputs of individuals with SCI using a 30 second, all out wheelchair ergometry test. Due to the lack of available data in this area, there was no baseline data available for comparison. It was determined that the higher the level of lesion, the greater the decrease in power output over the 30 seconds (Coutts and Stogryn, 1987). Wells and Hooker (1990) theorize that the lack of sympathetic cardio-acceleration resulting from a higher spinal cord lesion contributed to a slower increase in muscle blood flow and oxygen delivery. Although not directly related to anaerobic exercise, the decreased rate of muscle blood flow and oxygen delivery would result in an increase of anaerobic byproducts.

Arm crank exercise elicited a greater blood lactate concentration at a given submaximal power output and VO_2 level than cycling exercise (Sawka, 1986). This may be due to the difference in relative intensity of the two modes of exercise. Sawka also found that a subject's lactate threshold occurred at approximately 50% of their peak oxygen uptake during arm crank exercise, which was lower than for cycle exercise. Anaerobic threshold levels were reported to be lower for arm crank exercise (47-65% peak VO_2) than for cycling exercise (54-70% peak VO_2) (Davis et al, 1976; Reybrouck et al, 1975). Shephard et al (1989) determined that a decrease in active muscle mass would decrease the maximal rate of glycolysis. In addition, at anaerobic threshold, the corresponding heart rate was lower as the volume of active muscle was reduced.

4.12 Muscular Strength and Endurance

Strength was defined as the ability to sustain the maximum application of force against a resistance, where as muscular endurance was defined as the ability to perform repeated contractions against a load for an extended period of time (Fox et al, 1988). For individuals with a physical disability it was of vital importance to develop the functional muscle mass. The ability to overcome physical limitations such as doors, curbs, ramps and uneven terrain was of great practical importance for the wheelchair dependent individual (Wells and Hooker, 1990). Strength was as important if not more so, for peak performance in wheelchair athletes. In comparison to lower body muscle groups, the upper body muscle groups were relatively weaker. Muscular strength influenced upper body performance, allowing stronger individuals to achieve higher power outputs before becoming fatigued (Sawka, 1986).

In an investigation done by Janssen and colleagues (1993), a strong correlation was found between upper body strength, sprint power and aerobic power in persons with SCI. They concluded that this was probably due to shared dependency on active muscle mass. Similarly, Davis et al, (1984) indicated that isokinetic strength gains occurred in a population of disabled men, following eight weeks of arm crank training. Improvements were shown in both elbow flexion and extension, shoulder extension and the total work accomplished during shoulder flexion and extension. Due to the use of forearm muscles during wheelchair propulsion, hand grip strength seemed to be important for wheelchair dependent individuals. Schwartz and co researchers (1992) determined that hand-held dynamometer measurements could be used to determine forearm strength in SCI individuals. Wicks et al (1983) indicated that wheelchair athletes had average hand grip scores greater than that of able-bodied controls (able bodied men: 50-60 kg; able bodied women: 20-30 kg; wheelchair male athletes; 53-62 kg; wheelchair female athletes: 35-38 kg). A recent study conducted by Calmels and colleagues (1992) determined that at high velocity of movement (150 rads per second), paraplegic basketball players had significantly greater muscle strength of the elbow flexors and extensors than did able bodied basketball players. In addition, the muscle cross sectional area of the upper limbs was significantly greater in the paraplegic subjects than the able bodied subjects.

4.2 Testing Protocol Considerations

4.21 Arm Crank Versus Wheelchair Ergometry

As previously stated, wheelchair ergometry produced higher peak VO_2 and V_E than did arm crank exercise (Gass and Camp, 1983). However, both modes of exercise [illegible] near increases with increase in power output (Sawka et al, 19[illegible]). [illegible] seem that wheelchair ergometry was a more appropriate mode of exercise testing because it elicited a higher physiological response and imposed demands on the individual that were more specific to their mode of daily locomotion (Bhambhani et al, 1991). Arm crank ergometry also has many advantages. According to Sawka (1986), arm cranks can be easily set up and modified, are the most common mode of upper body ergometry reported in the literature, are a relatively simple mode of upper body exercise and the knowledge gained of the physiological demands of arm crank exercise could be used to understand the additional physiological demands imposed by other modes of upperbody exercise, such as wheelchair ergometry. Arm crank ergometers are safer for maximal testing than wheelchair and treadmill protocols and can be calibrated in terms of power output and, therefore, are more reliable.

4.22 Maximal Oxygen Consumption

Recent research examined the response of SCI subjects to continuous and discontinuous protocols for maximal testing. Some investigations determined that there was no significant difference between continuous and discontinuous protocols for determining maximal oxygen consumption (Hartung et al, 1993; Rasche et al, 1993; Sawka et al, 1982; Washburn and Seals, 1983). However, continuous protocols were more practical due to the decreased time requirement (Rasche et al, 1993; Washburn and Seals, 1983). More specifically, incremental, continuous exercise protocols seemed to be the optimal method for evaluating exercise capacity in wheelchair users (Hartung et al, 1993). Sawka and co researchers (1982) indicated that a continuous protocol at a speed of 70 revolutions per minute (rpm) was the most efficient for producing peak VO_2 values.

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APPENDIX B

Time Motion Analysis Data Summaries

Subject 1 Time Motion Analysis Data Summary

activity type	percentage	frequency	total time (sec)	mean (sec)	sdev (sec)	min time	max time
struggling	0.2036	187	1364	7.294	5.056	0.39	25.87
sprint w ball	0.007	17	47.03	2.766	1.86	0.44	8.12
sprint	0.1252	251	839.1	3.343	2.192	0.33	15.77
shooting w mov't	0.002467	6	16.53	2.755	1.422	1.05	5.44
shooting	0.007441	10	49.86	4.986	6.532	0.32	23.18
resting total	0.2545	89	1705.21	19.159	19.786	1.26	107.81
resting (bench)	0	0		0	0	0	0
resting (floor)	0.2545	89		19.159	19.786	1.26	107.81
gliding	0.2831	308	1897.05	6.159	5.135	0.28	28.67
intermission	0.1166	4	781.42	195.355	255.639	7.91	634

Subject 2 Time Motion Analysis Data Summary

activity type	percentage	frequency	total time (sec)	mean (sec)	sdev (sec)	min time	max time
struggling	0.1526	104	823.25	7.915	7.253	0.49	34.16
sprint w ball	0.00079	3	4.28	1.426	1.291	0.33	3.24
sprint	0.0471	90	254.39	2.826	2.412	0.39	13.18
shooting w mov't	0.00063	2	3.41	1.705	0.825	0.88	2.53
shooting	0.0201	13	[illegible]	8.352	12.259	1.15	42.46
resting total	0.5032	23	2713.93	117.997	208.937	1.26	849.53
resting (bench)	0.4781		2580.24				
resting (floor)	0.0252		134.09				
gliding	0.1904	115	746.62	6.492	5.689	0.28	29.94
intermission	0.1424	2	738.03	369.015	320.295	48.72	689.31

Subject 3 Time Motion Analysis Data Summary

activity type	percentage	frequency	total time (sec)	mean (sec)	sdev (sec)	min time	max time
struggling	0.1424	83	670.17	8.074	7.085	0.27	34.17
sprint w ball	0.00658	7	30.97	4.424	1.663	2.14	6.97
sprint	0.0689	88	324.18	3.683	2.785	0.33	13.29
shooting w mov't	0.00126	3	5.93	1.976	1.076	0.72	3.35
shooting	0.00978	5	46.01	9.202	11.742	2.03	32.62
resting total	0.4424	26	2081.14	80.043	141.045	2.69	507.12
resting (bench)	0.4336		2040.06				
resting (floor)	0.00885		41.08				
gliding	0.1906	112	896.58	8.005	7.377	0.28	34
intermission	0.1378	2	648.56	324.28	214.43	109.85	538.71

Subject 4 Time Motion Analysis Data Summary

activity type	percentage	frequency	total time (sec)	mean (sec)	sdev (sec)	min time	max time
struggling	0.05623	27	218.54	8.094	6.329	1.26	23.07
sprint w ball	0.002746	6	10.71	1.785	0.4007	1.21	2.53
sprint	0.03968	49	154.78	3.159	1.499	0.077	8.35
shoot w mov't	0.0003	1	1.21	1.21	0	1.21	1.21
shooting	0.0109	10	42.37	4.237	3.378	0.044	10.65
resting total	0.3221	23	2426.44	105.497	369.09	0.066	1805.62
resting bench	0.4068		1585.93				
resting floor	0.2153		840.51				
gliding	0.0809	46	315.54	6.859	6.855	0.82	27.63
intermission	0.1874	1	731.11	731.11	0	731.11	731.11

Subject 5 Time Motion Analysis Data Summary

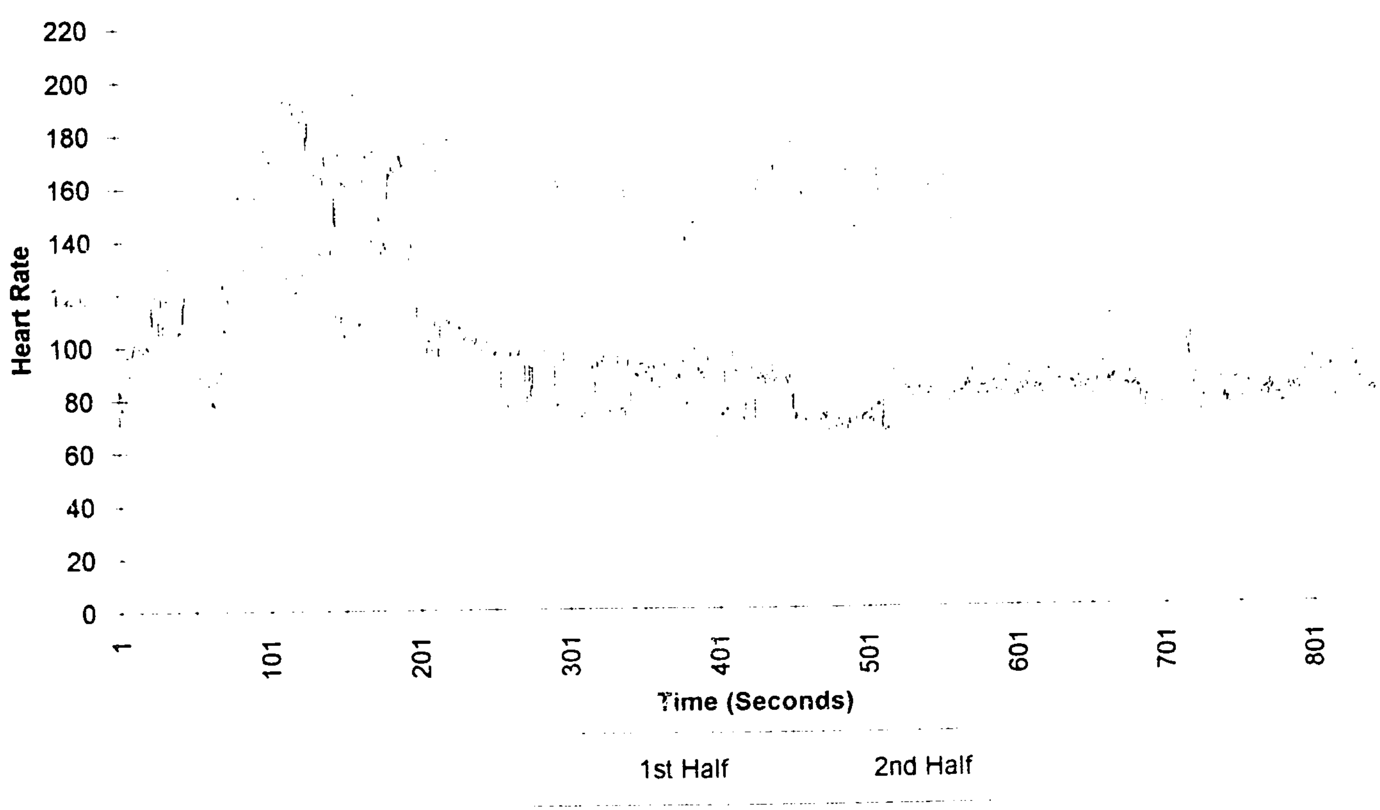
activity type	percentage	frequency	total time (sec)	mean (sec)	sdev (sec)	min time	max time
struggling	0.1993	150	1011.76	6.45	5.57	0.44	27.41
sprint w ball	0.00769	13	39.05	3.003	1.123	1.65	5.06
sprint	0.0981	160	498.15	3.113	2.413	0.44	13.68
shooting w mov't	0.00377	8	19.18	2.397	0.962	1.05	3.62
shooting	0.00681	7	34.6	4.942	8.022	0.98	24.56
resting total	0.2942	28	1493.2	53.328	137.542	2.58	582.32
resting (bench)	0.2483		1260.02				
resting (floor)	0.0459		233.18				
gliding	0.2684	190	1362.31	7.17	6.568	0.22	31.61
intermission	0.1216	1	617.2	617.2	0	617.2	617.2

Subject 6 Time Motion Analysis Data Summary

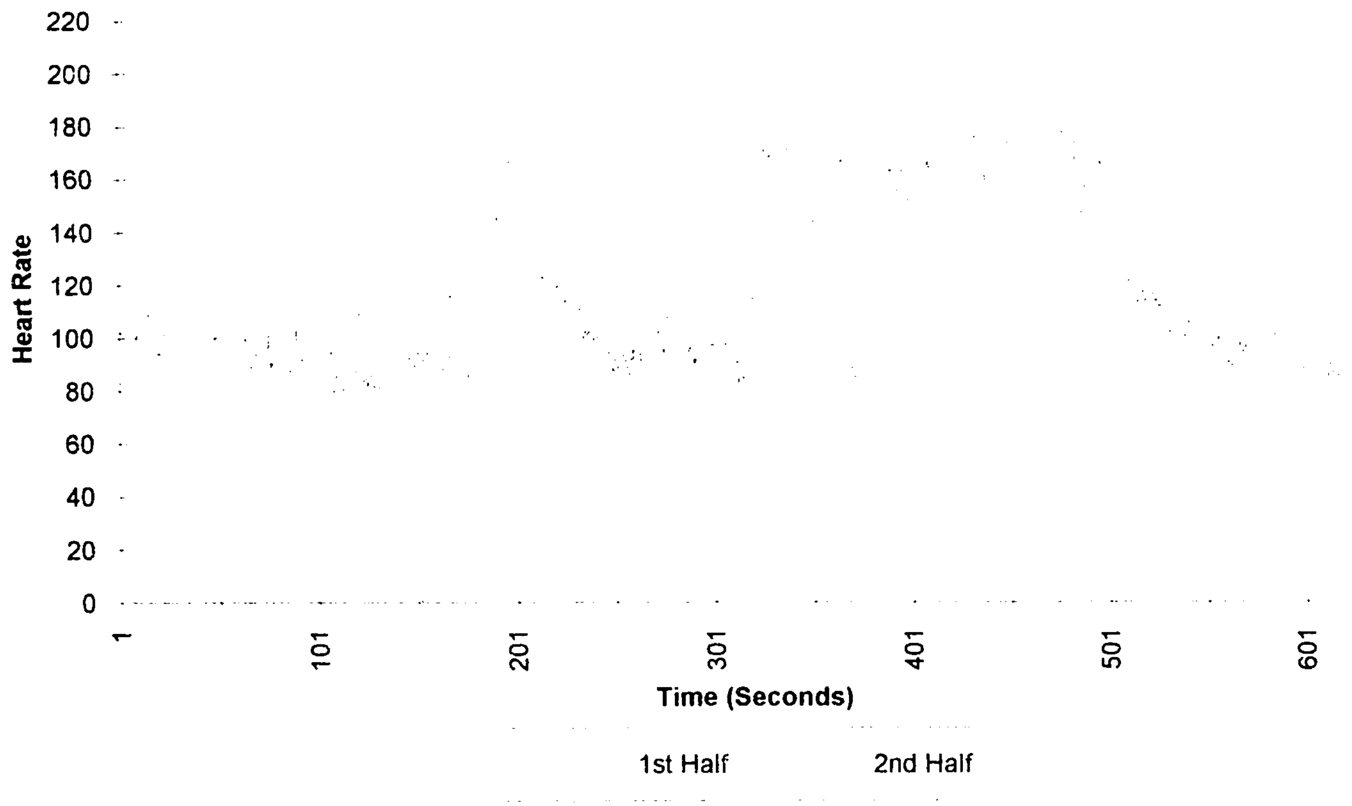
activity type	percentage	frequency	total time (sec)	mean (sec)	sdev (sec)	min time	max time
struggling	1372	93	610.33	6.562	6.121	0.82	25.32
sprint w ball	0.00697	12	31.03	2.585	2.323	0.44	7.63
sprint	0.0521	85	232.02	2.729	1.744	0.38	8.78
shooting w mov't	0.00696	7	30.98	4.425	2.369	0.93	7.91
shooting	0.00536	3	23.84	7.946	6.228	1.65	16.43
resting total	0.4583	28	2038.59	72.806	160.029	0.77	657.18
resting (bench)	0.4048		1800.02				
resting (floor)	0.0536		238.57				
gliding	0.1904	132	847.01	6.416	5.3007	0.28	30.98
intermission	0.1424	2	633.51	316.75	302.[illegible]45	13.84	619.67

APPENDIX C

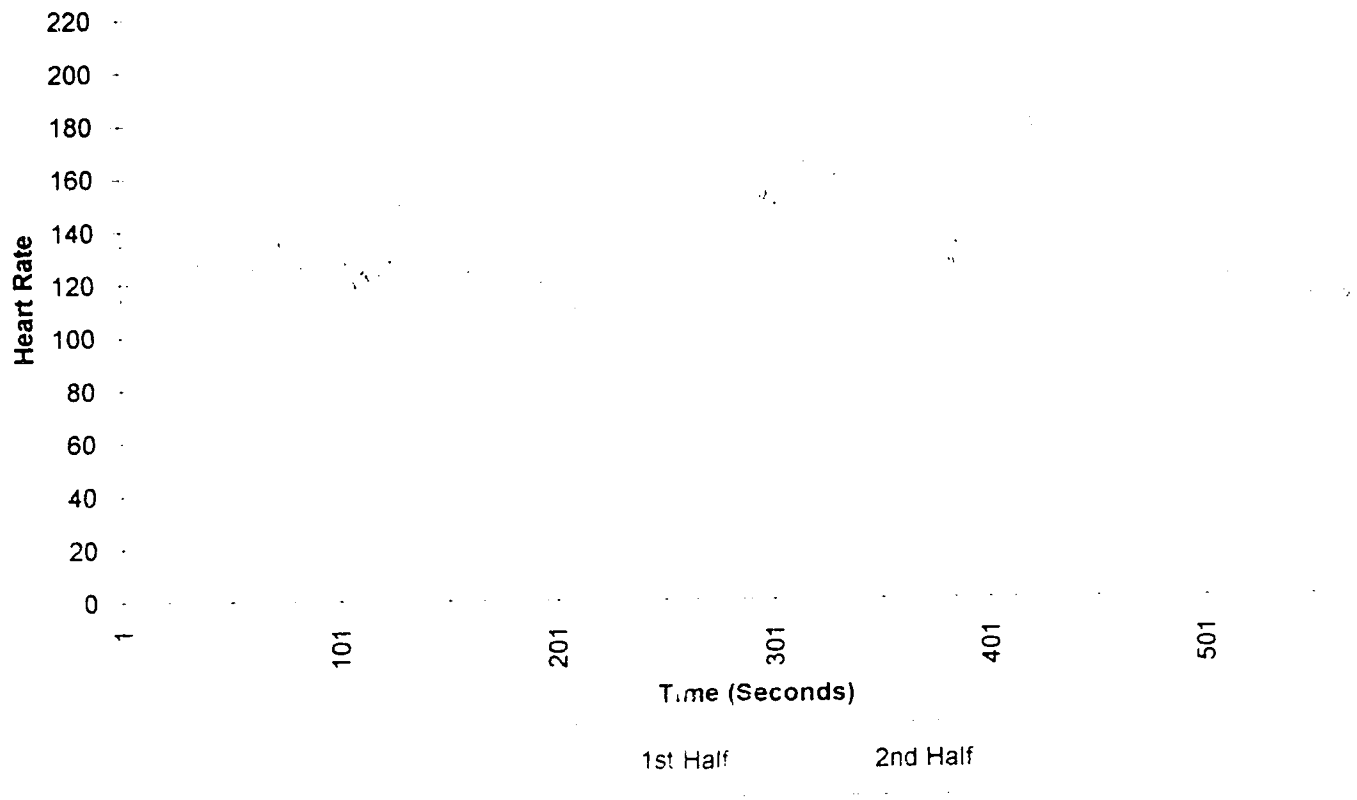
Subject 1 - HR During Wheelchair Basketball Game



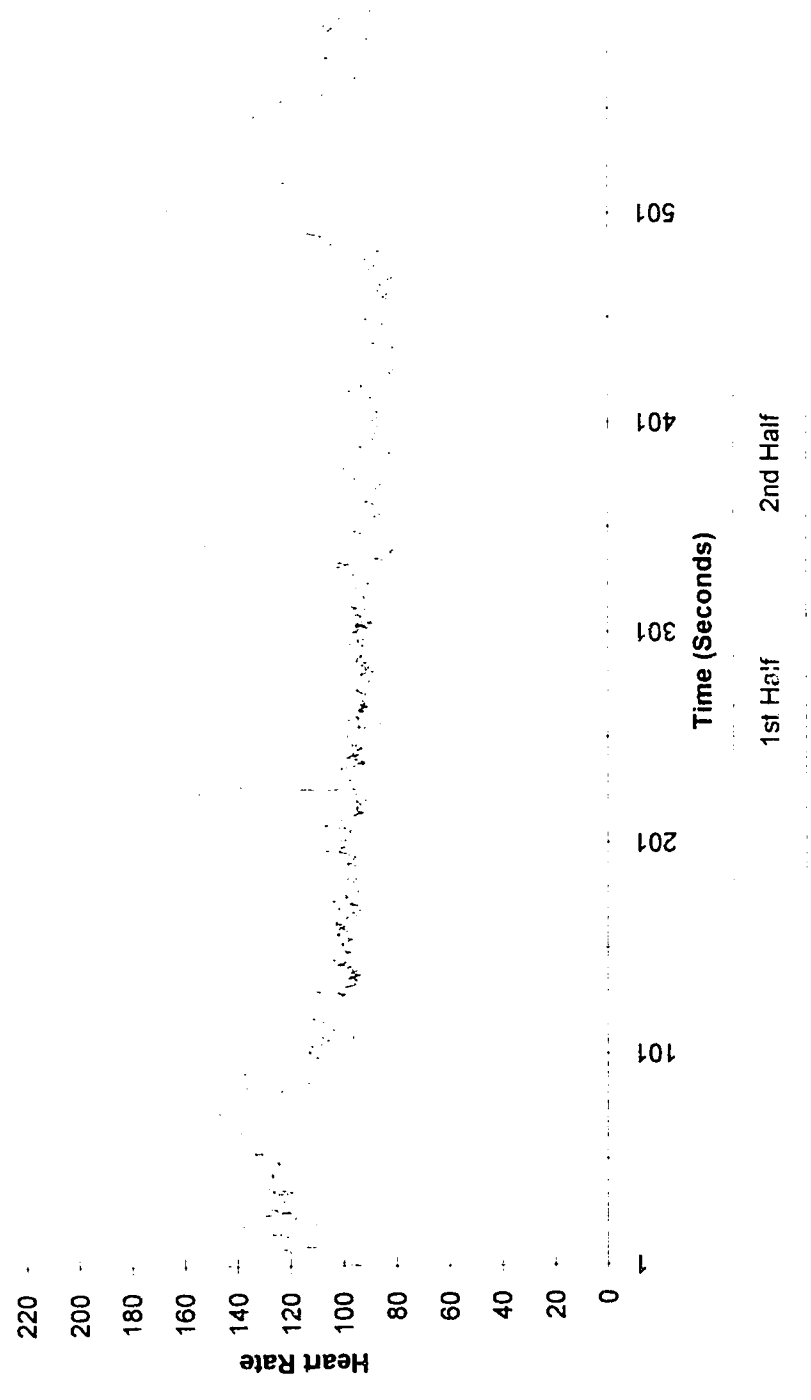
Subject 2 - HR During Wheelchair Basketball Game



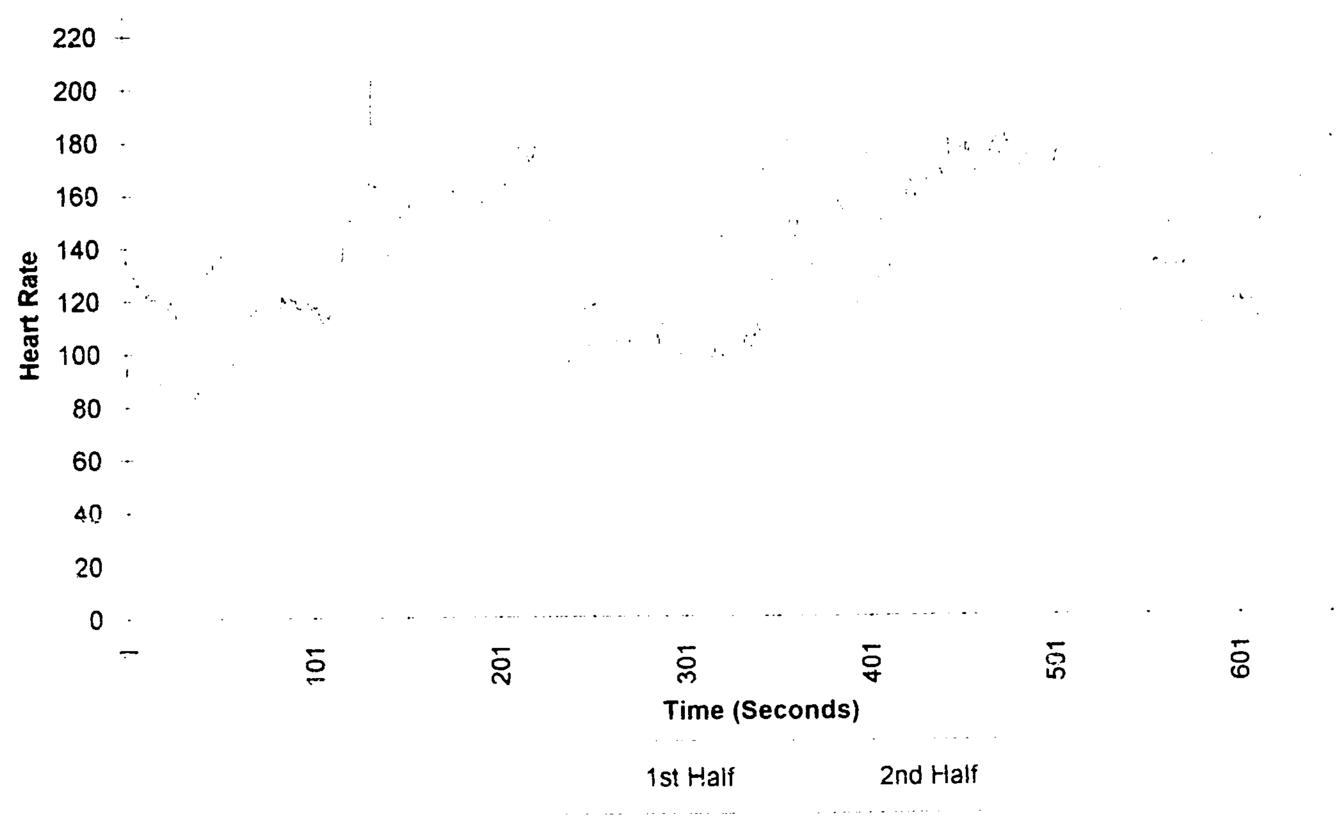
Subject 3 - HR During Wheelchair Basketball Game



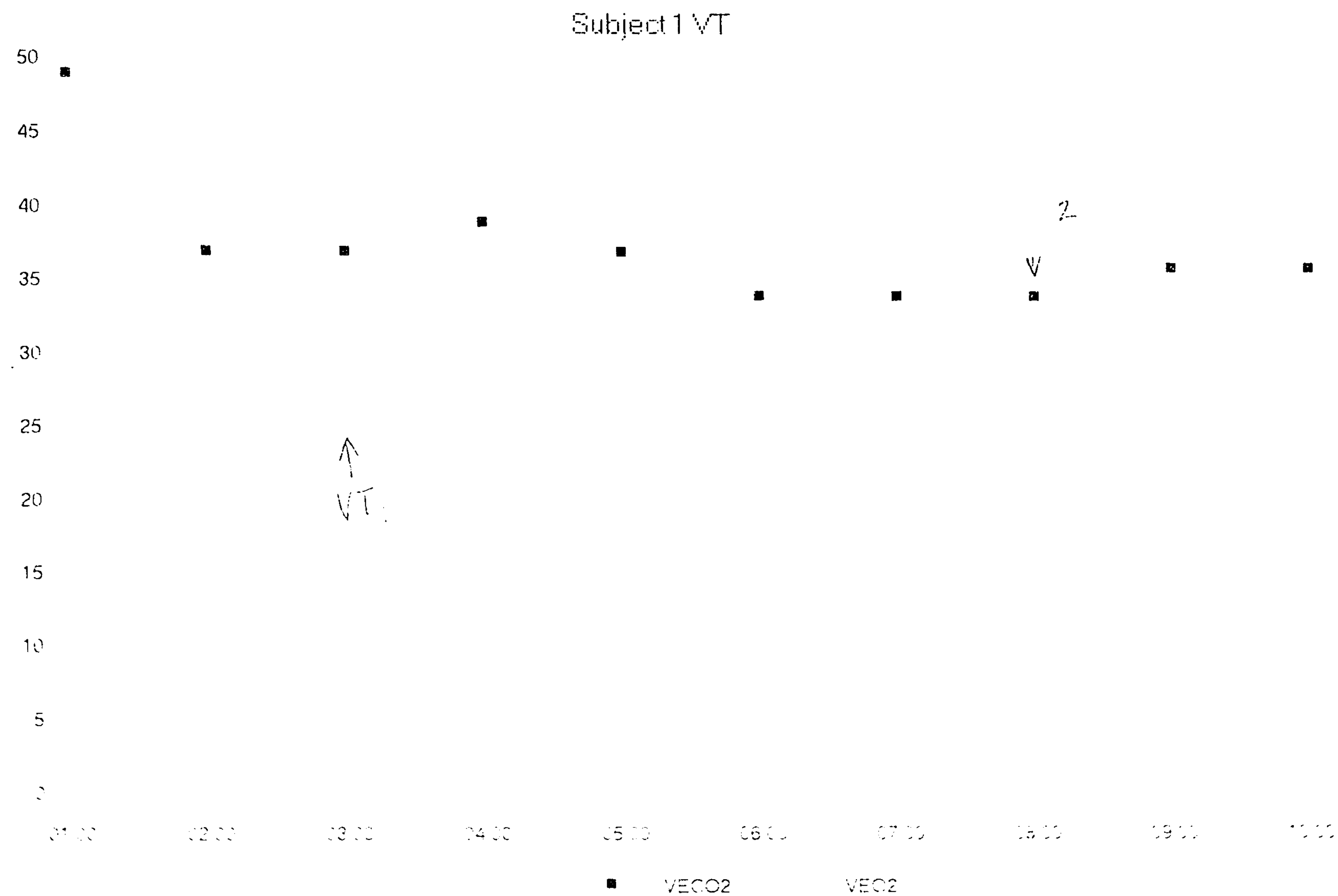
Subject 4 - HR During Wheelchair Basketball Game

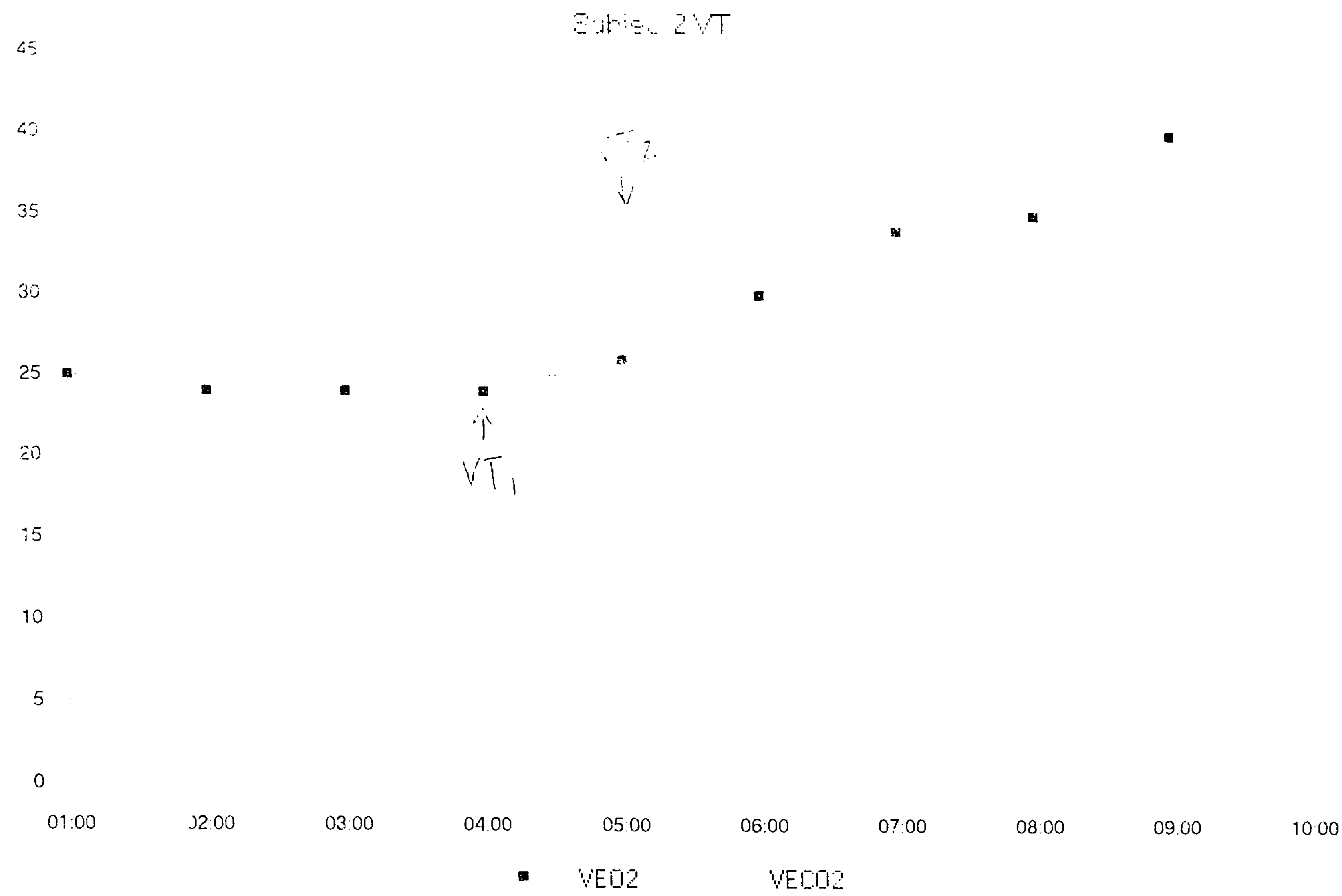


Subject 5 - HR During Wheelchair Basketball Game



APPENDIX D


Subject 1 VT
50
45
40
35
30
25
20
15
10
5
0
VT
VECO2
VEO2


Subject 2 VT
45
40
35
30
25
20
15
10
5
0
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
VT1
VT2
VE02
VEC02

Subject 3 VT

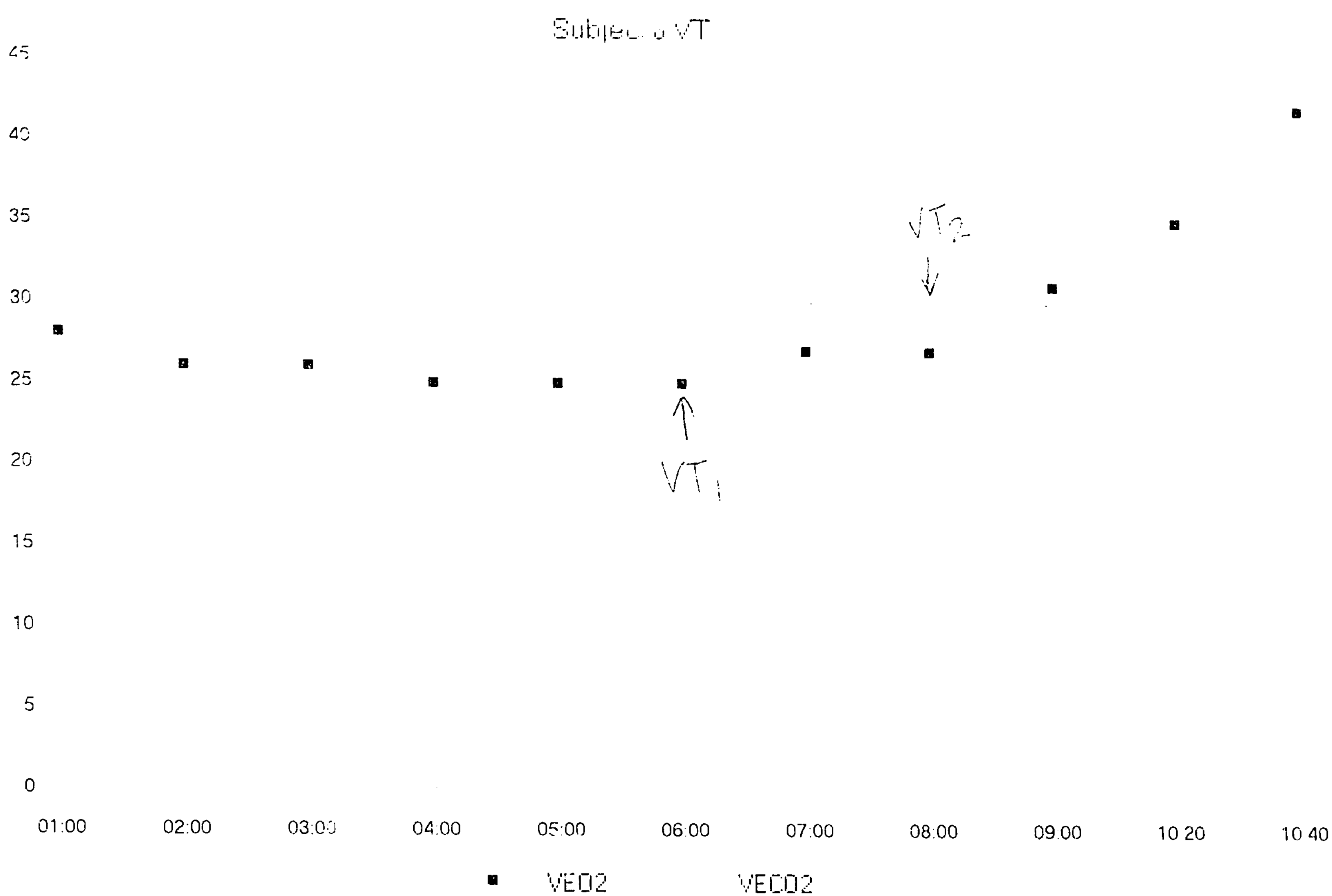
VE	VO2	VCO2	VE/VO2	VE/VCO2
30.2	0.585	0.598	51.62393	50.50167
28.5	0.706	0.578	40.36827	49.30796
29.5	0.894	0.63	32.99776	46.8254 ← VT1
32.7	1.011	0.719	32.34421	45.47983
34.6	1.[illegible]38	0.756	33.33333	45.7672
41.7	1.165	0.884	35.79399	47.17195
46.4	1.209	1.013	38.[illegible]883	45.80454
47.3	.245	1.033	37.99197	45.78896
51.6	1.305	1.129	39.54023	45.70416
54.6	1.343	1.191	40.65525	45.84383
55	1.431	1.267	38.43[illegible]	[illegible]3.40963 ← VT2
60.5	1.468	1.355	41.212[illegible]	44.64945
68.2	1.564	1.477	43.60614	46.17468
68.[illegible]	1.593	1.543	43.0634	44.45885
74.9	1.559	1.611	48.04362	46.49286
81.1	1.646	1.73	49.27096	46.87861
87.9	1.653	1.828	53.17604	48.08534
91.5	1.614	1.843	56.69145	49.64731
90.8	1.649	1.89	55.06367	48.04233
92.5	1.628	1.862	56.81818	49.67777
92.7	1.727	1.919	53.6709	48.30641
46.1	0.805	0.891	57.26708	51.73962
			??	??

Subject 4 VT

E	VO2	VCO2	VE/VO2	VE/VCO2	
32.7	1.001	0.709	32.66733	46.1213	
31	1.021	0.608	30.36239	50.98684	
52.7	1.395	1.187	37.77778	44.39764	
38.2	1.073	0.89	35.60112	42.92135	
44	1.222	0.996	36.00655	44.17671	
32.1	0.969	0.746	33.12693	43.02949	
51.4	1.212	1.093	42.40924	47.02653	
55.2	1.507	1.285	36.62906	42.9572	
46.8	1.375	1.085	34.03636	43.13364	
41.9	1.225	0.962	34.20408	43.55509	
56.5	1.421	1.246	39.76073	45.3451	
47.7	1.366	1.143	34.91947	41.73228	
38.3	1.161	0.905	32.9888	42.32044	
55.6	1.657	1.363	33.55462	40.79237	
55.9	1.893	1.426	29.52985	39.20056	
59.1	1.959	1.585	30.16845	37.28707	
62	1.974	1.666	31.40831	37.21489	
54.5	2.016	1.545	27.03373	35.27508	
56.7	2.146	1.673	26.42125	33.89121	VT1
56.7	1.886	1.633	30.06363	34.72137	
60.1	2.14	1.761	28.08411	34.12834	
51.1	1.88	1.469	27.18085	34.78557	
61.5	2.265	1.902	27.15232	32.33438	VT2
64.6	2.095	1.794	30.83532	36.00892	
81.9	2.245	2.079	36.48107	39.39394	
97.7	2.174	2.212	44.9402	44.16817	
95.2	2.692	2.46	35.36404	38.69919	
108	2.784	2.735	38.7931	39.48812	
99.8	3.124	2.708	31.94622	36.85377	
101.1	2.485	2.55	40.6841	39.64706	
30.4	1.004	0.797	30.27888	38.14304	

Subject 5 VT

	VO2	VCO2	VE/VO2	VE/VCO2	
39.8	1.119	0.818	35.56747	48.65526	
40.2	0.98	0.8	41.02041	50.25	
42.2	0.952	0.849	44.32773	49.70554	
41	1.124	0.819	36.47687	50.06105	
45	1.217	0.907	36.97617	49.51411	
33.7	1.136	0.747	29.66549	45.11379	
40.2	1.357	0.861	29.62417	46.6899	VT1
44.2	1.372	0.912	32.21574	48.46491	
48.4	1.52	1.043	31.84211	46.4046	
52.5	1.629	1.116	32.28975	47.13262	
62.7	1.809	1.299	34.66003	48.2679	
59.1	1.93	1.336	30.62176	44.23653	VT2
76.8	2.201	1.6[illegible]	34.89323	46.07079	
85.6	2.318	1.80[illegible]	36.92839	47.37133	
99.2	2.498	2.057	39.71177	48.22557	
108.7	2.695	2.337	40.33395	46.51262	
134.4	2.809	2.603	47.84621	51.63273	
133.7	2.766	2.588	48.33695	51.66151	
139.7	2.897	2.732	48.2223	51.1347	
137.6	2.855	2.785	48.19615	49.40754	
131.2	2.588	2.493	50.69552	52.62736	
			??		
			??		
			??		
			??		
			??		
			??		


Subject 6 VT
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25
20
15
10
5
0
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10 20
10 40
VT1
VT2
VEO2
VECO2