1-1-1992

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Order Number 1350545

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THE VALIDITY AND RELIABILITY

OF A 1-MINUTE HALF

SIT-UPS TEST

by

Maria Hortensia Diener

A thesis submitted in partial fulfillment

of the requirements for the degree of

Master of Science

in

Exercise Physiology

Department of Kinesiology

University of Nevada, Las Vegas

April, 1992

The Thesis of Maria Hortensia Diener for the degree of Masters of Science in Exercise Physiology is approved.

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University of Nevada, Las Vegas
April, 1992

Diener, Maria H., M.S., April 1992, Exercise Physiology

THE VALIDITY AND RELIABILITY OF A 1-MINUTE HALF SIT-UPS TEST (168 Pages)

Director of Thesis: Lawrence A. Golding, Ph.D.

The 1-minute full sit-ups test is currently being widely used in physical fitness test batteries to assess abdominal strength and endurance. Full sit-ups use the hip flexors as well as the abdominals and have been known to increase anterior pelvic tilt, and stress the lumbar vertebrae. Half sit-ups isolate the abdominal muscle group and do not stress the lumbar area. The purpose of this study was to investigate the validity and reliability of a 1-minute half sit-up test to allow for its implementation as a test of abdominal strength and endurance. Subjects (N=133) laid supine with knees bent at right angles and curled the spine by flexing the neck and the trunk until the inferior angles of the scapulae left the exercise surface. Subjects performed as many sit-ups as they could in one minute. Subjects participated in one of three experiments. A test-retest reliability study was conducted for two measuring devices, in which subjects performed the sit-ups twice using the same apparatus. An inter-apparatus reliability study between the two apparatus was conducted, in which subjects performed the sit-ups once for each measuring device. Results showed very high test-retest reliability for

both measuring devices (r=.967, r=.939), and high inter-apparatus reliability (r=.803). A validity study was conducted in which the subjects performed the half sit-ups test, the current YMCA full sit-ups test (concurrent validity), and a test of isometric abdominal strength (face validity). Concurrent validity was moderately high (r=.689), and face validity was moderate (r=.439). The results allow for the inference that the half sit-ups test is a valid and reliable measure of abdominal strength and endurance. Suggestions for further research include issues regarding validation of strength and endurance tests and further validation of the proposed protocol.

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Acknowledgements

The completion of this thesis would not have been possible without the help of the following people:

First words of appreciation go to my fellow graduate students ("second years" and "the kids"), Doug Duran, Stephen Krause, Charles Liggett, Beth Lynch, Aliza Pro, Dahn Shaulis (my favorite guinea pig), Nicole Smith, Kris Tucky, and Sherry Wulff, who patiently tolerated my ever changing moods during the tedious task of producing this manuscript. Special thanks to Pat McCollum for her special friendship and encouragement, and to Janice Matson for making these two years and oceans of paperwork more bearable and enjoyable.

To the faculty of the College of Human Performance and Development, thank you for the challenge and the priceless gift of your knowledge. Special thanks to Dr. Cinny Carruthers and Dr. Jack Young for their encouragement and smiles. To the members of my committee: Dr. Jerry Landwer, Dr. Dick Tandy, Dr. Jack Young, Dr. Lori Temple, and Dr. Larry Golding, thank you for the wise thoughts and guidance that helped make this project worthwhile.

Very special thanks to Lori Temple, for her editorial comments and her selfless friendship. To Larry Golding, for his valuable support, his relentless challenge, and for making the last two years the best educational experience of my life, a million "thank you's" are not enough to express my gratitude. And to my husband, Don, for being the most wonderful man on earth, putting up with my stressful days, and helping me through the rough times.

Chapter 1

Introduction

Physical fitness has often been defined as the composite of four dimensions: cardiorespiratory endurance, body composition, muscular strength and endurance, and flexibility (ACSM, 1991). Accepted physical fitness test batteries are designed to assess an individual's overall physical fitness. To assess the individual's muscular strength and endurance, it is usual to evaluate the muscular strength and endurance of large muscle groups. For example, a bench press test is designed to assess muscular strength and endurance of the upper body, and a squat test is designed to assess muscular strength and endurance of the lower body. Such tests usually consist of either completing a maximum number of repetitions in a limited amount of time, or completing a maximum number of repetitions to exhaustion.

Many fitness test batteries include a test designed to assess the muscular strength and endurance of the abdominal muscle group. Much emphasis has been placed on exercising the abdominals in exercise programs partly because of the aesthetic appeal of a flat, toned abdomen (Golding, Myers, & Sinning, 1989), and

partly due to the incidence of low back pain in the general population. It has been established that weak abdominal muscles, coupled with other factors such as poor hamstring flexibility and excess fat accumulation around the waist, can contribute to low back pain (Donchin, Woolf, Kaplan, & Floman, 1990; Fast, Weiss, Ducommun, Medina, & Butler, 1990; Helewa, Goldsmith, Smythe, & Gibson, 1990). The sit-up is a popular exercise included in exercise programs to acquire and maintain abdominal strength and endurance.

Generally, sit-up exercises are performed by flexing the upper trunk while lying supine. The conventional full sit-up is performed from the supine position with the knees extended by flexing the hips until the trunk is in a vertical position (Figure 1). The exercise can be completed with either the arms held across the chest, or the hands clasped behind the head. Feet can be supported either by a strap or held by a partner, or they can remain unsupported.

Electromyographic studies have shown that, in addition to the abdominal muscle group, the full sit-up exercise recruits the hip flexor muscle group (Flint, 1965; Godfrey, Kindig, & Windell, 1977; Gutin & Lipetz, 1969). These studies have shown that better isolation of the abdominal muscle group is obtained when partial curl-ups or half sit-ups are used. Described generally, a partial curl-up or half sit-up is characterized by the curling action of the upper spine, and the absence of hip flexion

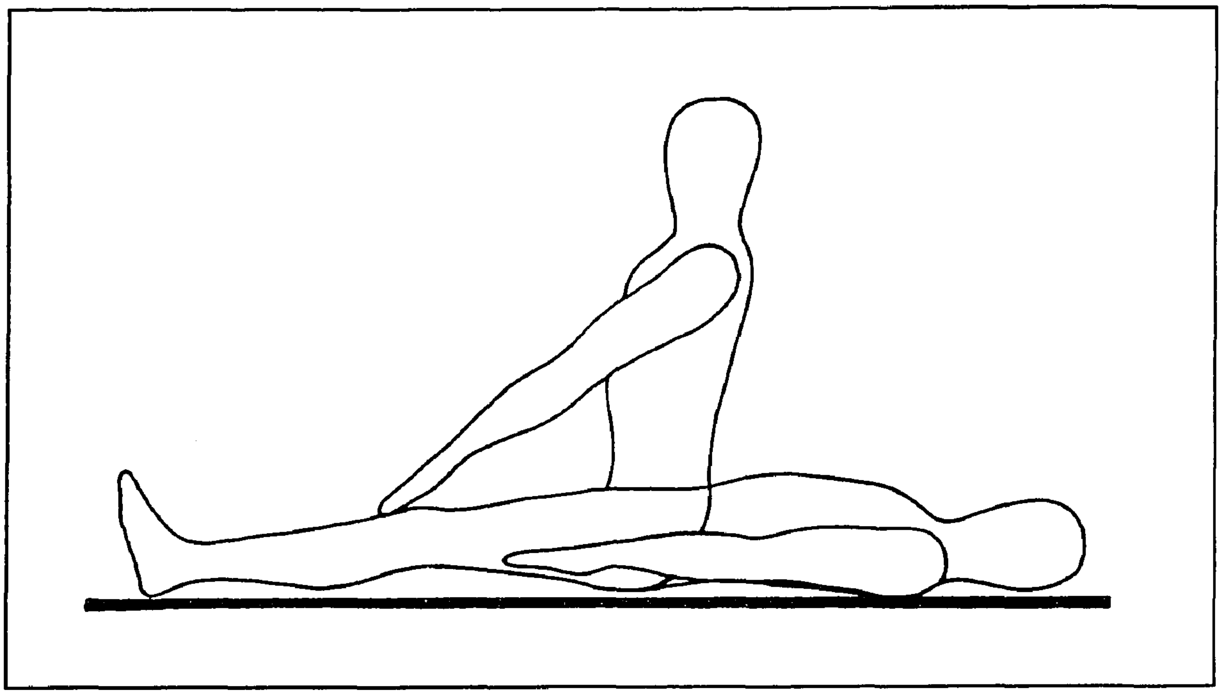


Figure 1 - Conventional full sit-up

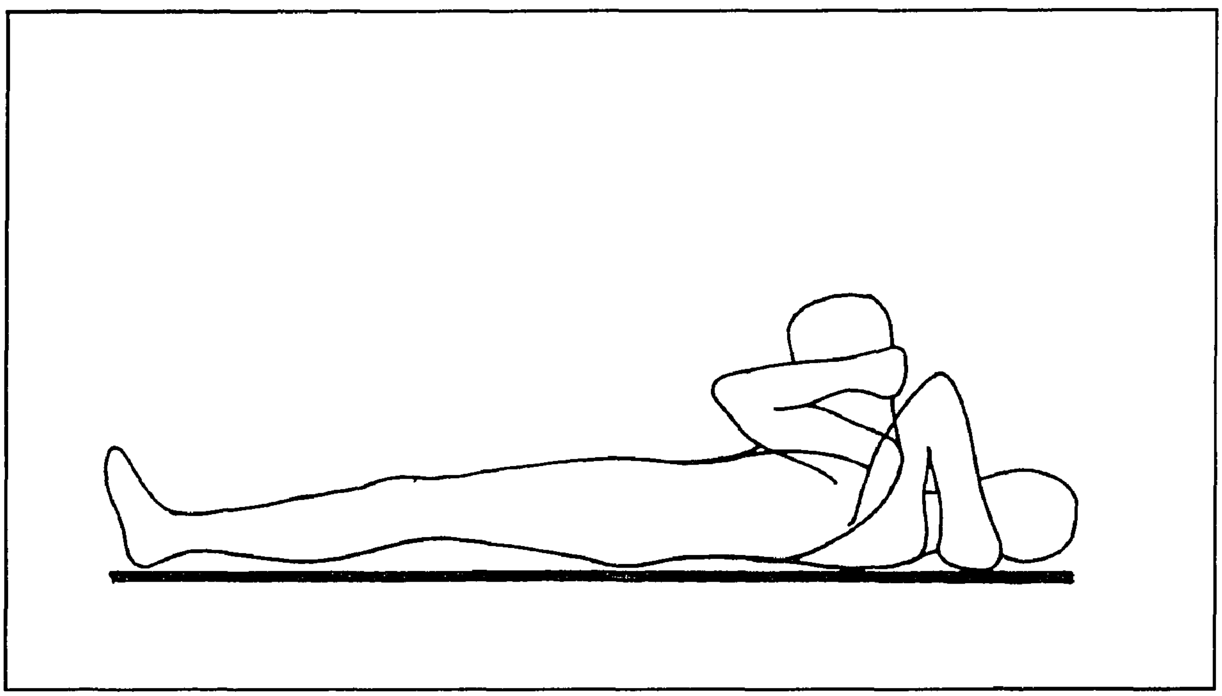


Figure 2 - Partial curl or half sit-up

(Figure 2). Thus, the subject's scapulae lift from the exercise surface to approximately 30° to 45°, but the lower trunk does not (Flint, 1965; Godfrey et al., 1977; Gutin& Lipetz, 1969). Many variations of full and half sit-ups exist and will be discussed further in a later chapter.

Need for the study

The use of full sit-ups as a regular exercise has declined in recent years because of possible stress to the lower back brought about by anterior pelvic tilt (Flint, 1965; Helewa et al., 1990; Le Veau, 1973; Rasch & Allman, 1972). This stress occurs when the initial phase of the sit-up is attempted. The psoas, a hip flexor and lumbar spine flexor, can under some circumstances hyperextend the lumbar spine. When in a supine position contraction of the psoas can overpower weak abdominal muscles, resulting in hyperextension of the lumbar vertebrae (Logan, 1965). This phenomenon is sometimes referred to as "the psoas paradox" (Rasch & Burke, 1974). Because the purpose of exercise is not to aggravate the lower back, and because a large segment of the population have low back problems, it is more desirable, while exercising, to do partial curls (half sit-ups).

Partial curls recruit a greater proportion of the abdominal muscle group (rectus abdominis, external and internal obliques), and when performed with the lower limbs elevated or flexed, employ less action of the hip flexors than full sit-ups (Flint, 1965;

Halpern & Bleck, 1979; Walters & Partridge, 1956). In addition, the initial strain on the lower back when initiating the sit-up, is minimized when partial curls are performed with the lower limbs elevated or bent at the knee joint at an angle of 90° or greater (Ricci, Marchetti, & Figura, 1981). Since partial curls and not full sit-ups are used in most exercise programs, it would be of value to develop a standard test of muscular endurance that utilizes partial curls.

The full sit-ups test has been standardized and it is fairly easy to control: the subject, starting in a supine position with the legs bent at right angles and the hands behind the head, touches opposite elbow to opposite knee, and then returns the shoulders to the floor (Golding et al, 1989). Partial curls are more difficult to control. Some subjects will curl up at a greater angle, lifting most of their trunk from the floor, and some will barely nod their head, leaving the scapulae down. A technique for reliable testing with partial curls needs to be developed, so that all subjects are curling about the same amount, and thus exerting the same effort. Since full sit-ups have been replaced by half sit-ups in most exercise programs, the standardization of a test of abdominal strength and endurance employing half sit-ups has become desirable and necessary.

Partial curl-up testing protocols have been proposed (Diener & Golding, 1991; Faulkner, Sprigings, McQuarrie, & Bell, 1989; Reebok, 1991), however, there have

been problems identified with the reliability, objectivity, and applicability of such protocols. The need remains for an objective, practical, and reliable partial curl-up test of abdominal strength and endurance.

Purpose of the study

The purpose of this study was to develop a valid and reliable test of abdominal strength and endurance. Reliability refers to consistency in the measurement process across subjects, examiners, and testing situations. Two types of reliability were chosen as appropriate for this test:

1) Test-retest reliability represents the consistency of the procedure across testing sessions. Since the half sit-ups test is likely to be used in repeated occasions as an individual's abdominal strength and endurance progresses throughout an exercise program, test-retest reliability was chosen to assure consistency of procedure across testing sessions (Anastasi, 1988).

2) Inter-apparatus reliability refers to the consistency of the procedure across measuring devices. Two measuring devices were developed for this investigation. Since the individual performance may be measured under different circumstances, inter-apparatus reliability was chosen to assure consistency of measures across apparatus (Anastasi, 1988).

3) Validity refers to whether the instrument is actually measuring the intended parameter, in this case, abdominal strength and endurance. The concurrent validity of the proposed test was measured by correlating the scores of the new test with those of a current standardized test. The YMCA full sit-up test protocol was chosen due to its replicability, accepted usage, and ease of implementation. Face validity was investigated by measuring isometric abdominal strength by using a load cell, cable, and a strength table, and correlating those scores with the half sit-ups test. Since the half sit-ups test measures abdominal strength *and* endurance, the correlation was expected to be moderate (Anastasi, 1988).

Limitations

1) No electromyographic (EMG) measurements were made in this study. The relevant literature includes studies in which several types of sit-up exercises have been documented with appropriate EMG measurements. Several of these studies include EMG measurements of the exact procedure followed in this study (Flint, 1965; Godfrey et al. 1977; Gutin & Lipetz, 1969; Walters & Partridge, 1956).

2) Only apparently healthy individuals were recruited as volunteers. The adaptation of this test for individuals suffering from low back pain or other limitations which prevent them from performing the half sit-ups as described in this study, were not addressed.

Chapter 2

Review of the Literature

The measurement of athletes and athletic performance dates back to the Greek olympiads. In addition to measuring speed of racers and height of jumps, the search began for indicators of athletic prowess through the measurement of man (Massey, 1970). Early measurements were mostly concerned with the anthropometrical characteristics and strength of athletes (Clarke, 1959; Fleishman, 1964; Massey, 1970).

One of the pioneers in measurement was Dr. Edward Hitchcock, who is said to be the father of physical education measurement in the United States. He administered the first physical fitness battery to students attending Amherst College starting in 1861. Measures included height, weight, finger reach, chest girth, lung capacity, and pullups (Massey, 1970). Advocates of physical fitness in the 19th century emphasized strength and body development as precursors of good health (Clarke, 1959; Davis, 1964; Massey, 1970).

History of Strength Testing

Cureton (1947) defined strength as the capacity of the human body to overcome a resistance. The study of strength measurements stemmed from the search for factors affecting the performance of athletes, and the attainment of a body with "ideal" proportions. Dudley Sargent had such interests. In the early 1880's Sargent switched his interests from anthropometry to strength testing (Davis, 1964; Massey, 1970). The Intercollegiate Strength Test, developed by Sargent, measured the strength of legs, back, and hand grip using a spring dynamometer, and used dips and pull-ups to measure arm strength (Davis, 1964; Hunsicker & Donnelly, 1955; Massey, 1970). Rogers and later McCloy modified the battery calling it the Physical Fitness Index. The Rogers strength battery and the McCloy strength battery are still used in physical fitness test batteries today (Clarke, 1959; Davis, 1964; Mathews, 1973; McCloy & Young, 1954).

Strength testing instruments developed as the need to measure strength became more demanding. The spring dynamometer was developed as early as 1807 by Desaguliers, and later modified to include a dial where the amount of compression exerted on the spring could be easily read (Davis, 1964). In the late 1880's a hydraulic universal dynamometer was developed by Kellogg. The apparatus had a mercury filled cistern with a float and a dial that registered the level of the mercury as pressure

was applied (Bornard, Cozens & Hagman, 1949; Davis, 1964). The universal dynamometer was large and expensive and the testing sessions were lengthy.

H. Harrison Clarke first used the tensiometer, a system of straps and pulleys attached to an aircraft control cable tensiometer. The tensiometer read the tension applied to the cable as the subject pulled with the straps attached to the tested limb. The tension measurements were calibrated to read units of resistance such as kilograms or pounds (Clarke, 1966; Davis, 1964). Clarke's system of straps and pulleys isolated particular muscle groups, which would exert force against the cable tensiometer. The tensiometer is still in use today.

Other important names in the origin and development of strength testing include Martin (1915), who introduced resistance to a pulling force as a measure of strength. The test required that the subject resist a pull exerted by the experimenter. Rogers (1925) developed the Strength Index (SI), comprised of six tests of strength including push-ups, pull-ups, and hand grip strength. McCloy (1934) employed chins and dips from a parallel bar, and Mathews and Brown (1953, 1954) used pull-ups, dips, and sit-ups as part of a strength test battery (Davis, 1964).

It was not long before researchers began to distinguish between strength that could be measured by a dynamometer and strength needed to pull-up or push-up one's own weight repeatedly. A basic requirement for the measurement of strength, is to test

an isolated muscle group (Van Huss & Heusner, 1970; Meyers & Piscopo, 1963). Thus, most strength measurements reflect the particular strength of one muscle group.

Three types of strength have been identified:

1) Explosive strength was defined as the capacity to exert maximum effort in one single burst. Tests for this type of strength included the standing broad jump and the vertical jump (Cumbee & Harris, 1954; Fleishman, 1964; McCloy, 1934).

2) Dynamic strength (concentric, isotonic) was defined as the ability of a muscle group to exert repeated force until fatigued. Tests for this type of strength included pull-ups and rope climbs, and later tests involving the trunk such as sit-ups and leg-lifts (Brogden, Burke & Lubin, 1952; Fleishman, 1964). Dynamic strength testing also includes tests such as the 1 repetition maximum (1RM), in which the greatest amount of weight that a subject can lift one time is determined by trial and error (DeLorme & Watkins, 1952), and the NK table for measuring knee extension strength (Nolan & Kuckhoff, 1954).

3) Static strength (isometric) was defined as the maximum force exerted against a measuring device which could be held briefly. The movement of the limbs exerting the force during this contraction is very limited or non-existent. Tests of static strength require some measuring device such as a dynamometer or tensiometer (Cureton, 1947; Fleishman, 1964; Henry, 1960).

A new type of strength measuring device emerged in the mid 1950's. The device permits measuring the strength of a contraction throughout the entire range of movement, by artificially controlling the speed of contraction. Isokinetic strength measurement devices such as the sophisticated Cybex (Lumex Inc., 1975), permit researchers to gather information about peak torque of a contraction, the angle at which that peak is achieved, the rate at which the torque is applied, and the work done during the contraction (Burdett & Van Swearingen, 1987; Moffroid, Whipple, Lowman, & Thistle, 1969). These devices are used for both isokinetic strength testing and exercise.

Although explosive, dynamic, and static strength are measured differently, interrelations between the different types of strength have been reported by several researchers. There exists some controversy about the magnitude of the relationship among the different types of strength, however, most researchers agree that strong individuals are likely to be able to show higher strength in any test of strength (Berger & Henderson 1965; Harris, 1937; Hunsicker & Donnelly, 1955; Smith, 1961).

Knapik, Wright, Mawdsley, and Braun (1983), studied the relationship between isokinetic, isometric, and isotonic strength in knee and elbow extension. The average variance (Pearson r^2 x 100) shared by isometric and isotonic strength was 48%; between isokinetic and isotonic strength, 53%; and, between isometric and isokinetic

strength, 62%. The authors concluded that results obtained with one mode of strength testing may adequately predict results obtained in a second mode of strength testing at the same joint angle.

The relationship of power (work/time) to static and dynamic strength was studied by Berger and Henderson (1965), who concluded that static (r=.64) and dynamic strength (r=.71) were equally related to power. The correlation between static and dynamic leg strength was .60. The authors stated that the greater the strength required by a particular test, the greater the correlation with a measure of static strength (e.g., vertical jump and static leg strength would correlate better than sit-ups and static abdominal strength).

Bender and Kaplan (1965) determined that the performance in a dynamic task could be predicted from a measurement of isometric strength. Although the correlation coefficient between the measures of isometric strength and dynamic performance were not computed, the authors were able to predict success or failure in a chinning task from the isometric strength measure.

In summary, although different types of strength have been identified, the relationship between the kinds of strength within an individual is high. Strength research is controversial due to the different types of strength, lack of standardization among measures of strength, and differences in protocols used in different studies.

Measurement of Strength

Power, or explosive strength, is measured by explosive movements such as the vertical jump and the standing broad jump. Although the dependent variables are usually expressed in terms of distances, power lifts are also considered tests of explosive strength. These tests include the snatch lift and the clean-and-jerk lift where the dependent variable is the amount of weight lifted (Johnson & Nelson, 1986).

Static or isometric strength can be measured by instruments against which force can be applied while the movement of the limb is limited. Such devices include (Figure 3): 1) spring scales; 2) dynamometers; and 3) cable tensiometers. Spring-scales measure the amount of pull exerted on a spring and can be adapted to measure leg, back, pull-up, curl, and leg press strength (Johnson & Nelson, 1986; Mathews, 1973; McCloy & Young, 1954). Dynamometers work under the same principle as spring scales, and measure the compression exerted on a spring. Some dynamometers use the principle of the cable tensiometer, described below (McCloy & Young, 1954; Mathews, 1973). Dynamometers have been adapted to measure hand-grip strength, leg strength, and back strength (Van Huss & Heusner, 1970). The original spring steel dynamometers were found to be inadequate for testing young children by Smedley, who modified the device. The Smedley hand-grip dynamometer was adjustable and allowed for testing of different size hands (Hunsicker & Donnelly, 1954).

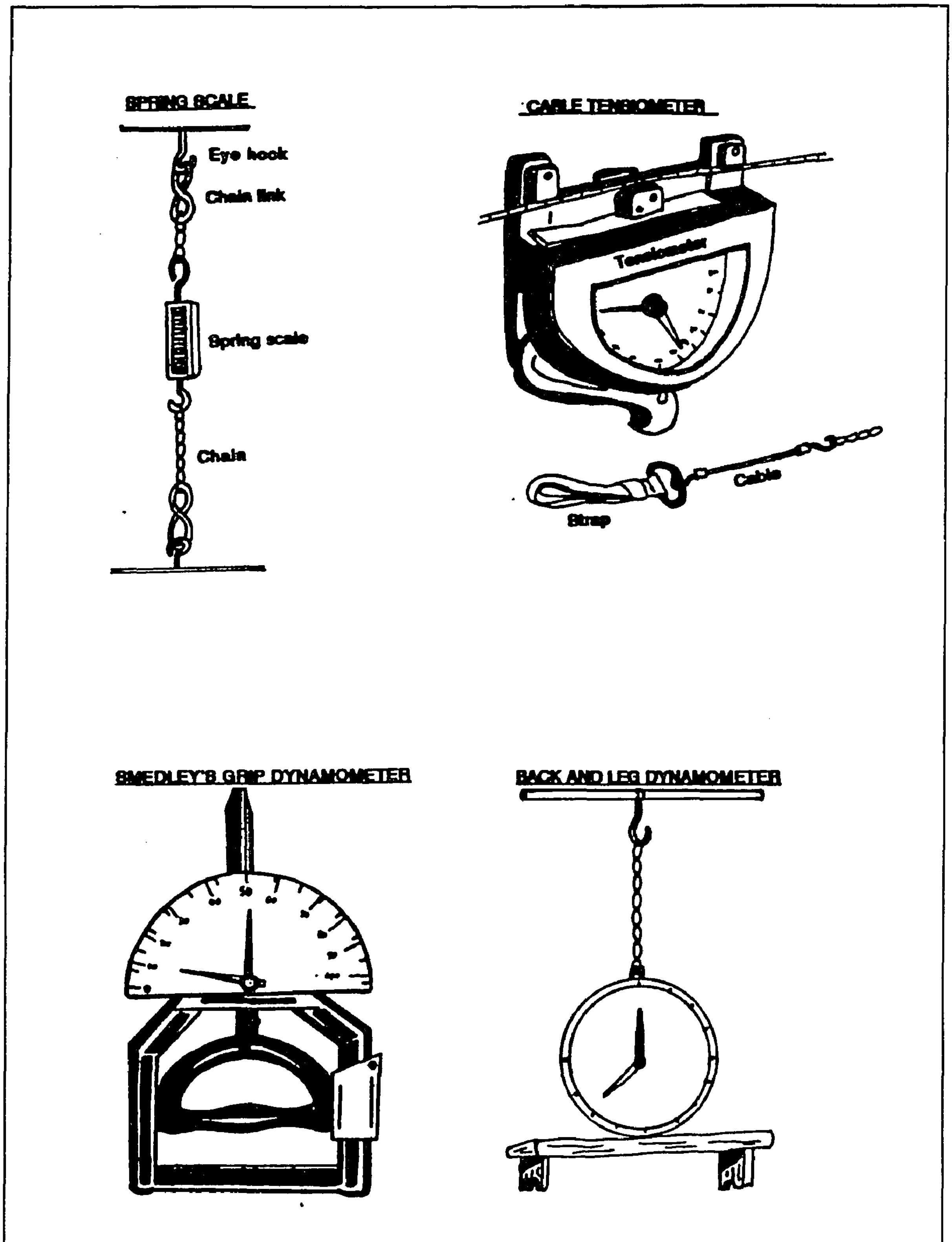


Figure 3 - Strength measuring devices (Adapted from Johnson & Nelson, 1986)

The most popular dynamometer used in physical fitness test batteries is the hand-grip dynamometer, a test that is inexpensive and quick to administer (Van Huss & Heusner, 1970; Kroll, 1962). Cable tensiometers measure the tension exerted on a cable. Usually one end of the cable is attached to an immovable anchor, and the other is strapped to the limb tested (Clarke, 1966; McCloy & Young, 1954). Clarke adapted the cable tensiometer to measure the strength of all muscle groups with the use of a device called a strength table. The table assures consistency of testing procedures and subject positioning.

Two other devices are used for measuring strength, hydraulic systems measure the pressure exerted by a loose-fitting cylindric float placed in a closed fluid reservoir. The subject controls a system of mechanical levers, forcing the float down into the mercury at a certain pressure. The pressure is read on a gauge. The Kellogg Mercurial Dynamometer operated under this principle, and measured the strength of 22 muscles and muscle groups (Hunsicker & Donnelly, 1955; Van Huss & Heusner, 1970).

Isotonic or dynamic strength is measured by permitting a limb to achieve full range of motion. Delorme's (1951) 1-RM (1-repetition maximum) tests include the bench press, military press, squat lift, and others. The 1-RM is determined by adding or subtracting weight from a barbell, until the subject can perform only one repetition (Johnson & Nelson, 1986; McCloy & Young, 1954; Van Huss & Heusner, 1970).

In early test batteries, such as the Intercollegiate Strength Test, the Rogers Strength test, and the McCloy Strength Test, repetitive dynamic movements were included as a measure of dynamic strength. These included pull-ups (chins), push-ups, dips, and sit-ups (McCloy & Young, 1954). Some test protocols use repetitions achieved in a limited amount of time, the criticism being that an endurance component is introduced (Johnson & Nelson, 1986). However, for practical reasons, field test batteries often include time limited dynamic repetition tests (McCloy & Young, 1954). A more accurate measure of strength when using such exercises is obtained by attaching weight to the athlete until the exercise can be performed only once, as in the 1-RM protocol. The dependent measure used in these tests usually includes a ratio of the athletes weight and the added weight (body weight divided into additional weight lifted) (Johnson & Nelson, 1986; Mathews, 1973).

In summary, instruments and tests to measure strength are plentiful and diverse. For most physical fitness batteries, speed of administration, cost of apparatus, and portability interact to determine which set of instruments or tests are used for any given purpose.

Muscular Strength and Endurance

There are some events in which an athlete is asked to exert a maximal strength effort once (e.g., powerlifting, shotput, etc.); however, in most athletic events, athletes

are asked to repeatedly contract muscle groups at a less than maximum intensity. This type of effort requires muscular strength as well as muscular endurance (Hunsicker, 1974). The Intercollegiate strength tests developed by Sargent favored the gymnasts for whom the tests were developed, who consistently scored better in the battery than other athletes. These tests involved calisthenic exercises such as chin-ups and dips, performed with added weighs attached to the body. The score was the total weight divided by the gymnast's weight. Since gymnastics training involves practicing these exercises, and the weight of the gymnast is often proportional to their strength (as opposed to football linesmen), gymnasts were given an unfair advantage. In order to be fair to other athletes, muscular endurance and speed were added to the testing batteries (Davis, 1964).

Muscular endurance is defined as the ability of a muscle to maintain a certain degree of contraction for a period of time (static), or to perform repeated contractions against some type of resistance (dynamic) (ACSM, 1991). However, muscular strength and muscular endurance are very closely related. In exercising to attain muscular strength, individuals have to repeatedly perform a certain movement. The relationship between muscular strength and muscular endurance has produced correlations from .76 to .95 (Knapik, 1989). Those individuals with high muscular strength also showed high muscular endurance for the muscle groups tested.

Although the relationships have not clearly been defined, it has been found that subjects that trained to gain strength, also achieved improvements in muscular endurance (Johnson & Nelson, 1986). Conversely, Clarke (1966) and colleagues found strength gains in athletes whose exercise programs were designed to develop muscular endurance. Although a strength program (high resistance, low repetitions) will develop more strength, and a muscular endurance program (high repetitions, low resistance) will develop more endurance, the athlete will gain both muscular strength and endurance as a result of either form of training (Anderson & Kearney, 1981; Johnson & Nelson, 1986). Anderson and Kearney (1981) found improvements in strength and endurance in three criterion measures (40% of 1-RM, 1-RM, and bench press test) in athletes subjected to different training protocols (strength, endurance, and strength and endurance).

The close relationship between muscular strength and muscular endurance is based on the fact that most athletic and recreational events require the combination of both muscular strength and endurance. Therefore, from a practical standpoint those tests which employ repetitive dynamic contractions of a muscle group, would be the most suited to include in physical fitness testing batteries (Hunsicker, 1974; Knapik, 1989). Tests of muscular strength and endurance were also named "motor

fitness" tests, and emphasized the capacity of an individual to perform vigorous work (Knapik, 1989; Mathews, 1973).

In summary, muscle strength and muscle endurance are closely associated. This relationship stems from the fact that most activities require employment of both strength and endurance. Tests of muscular strength and endurance reflect an individual's capacity to perform in athletic competition and, more generally, to perform vigorous work.

Measurement of Muscle Strength and Endurance

The marriage of muscular endurance to muscular strength favored the use of calisthenic based tests such as the sit-up, dip, and the push-up tests to assess the performance of athletes and the general population (McCloy & Young, 1954). Tests of muscular strength and endurance usually require the involvement of a large muscle group (abdominals, hip flexors, arms and shoulders) (Johnson & Nelson, 1986). Some tests require the subject to perform as many repetitions as possible in a limited time period, whereas others require that the subject perform repetitions until exhausted (ACSM, 1991).

Tests of muscular strength and endurance may use a fixed weight regardless of the subject's strength in order to make comparisons among the performance of participants. The bench press test and the arm curl test for example, are used to assess

upper body strength. A popular protocol requires that the subject lift a fixed weight at a certain cadence until either the cadence cannot be kept, or the subject is exhausted (Golding et al., 1989).

Other tests use the performer's body weight as resistance, and require that the subject pull-up, push-up, or dip their body without added weight. Pull-up tests measure the muscular strength and endurance of the anterior arms and chest (Golding et al., 1989), and require the subject to lift their body weight while hanging from a bar, until their chin reaches the bar. The subject usually performs to exhaustion (Johnson & Nelson, 1986; McCloy & Young, 1954). Push-up tests measure the strength and endurance of the posterior arms, chest, and shoulders (Golding et al., 1989), and require that the subject push their body weight up from a prone position, while maintaining a straight body. The subject's chest returns to the prone position after each repetition, and the total number of push-ups are counted (Johnson & Nelson, 1986), or the number of push-ups performed in a limited time are recorded. Dips require upper body strength and endurance, and require that the subject lower and raise their body weight from a set of parallel bars (Johnson & Nelson, 1986; Mathews, 1973; McCloy & Young, 1954). Sit-ups tests also use the performer's body as resistance and will be discussed in greater detail in a later section.

It is important to distinguish between muscular endurance and cardiovascular endurance, although the two are not completely separate events. Whereas many sports and activities require both types of endurance for good performance, cardiovascular endurance involves the ability of the athlete to tax the entire respiratory and circulatory system. Tests of cardiovascular endurance employ as many muscle groups as possible, in fact, the more muscle groups employed, the better the test (ACSM, 1991). Muscular endurance refers to the capacity of a particular muscle group to engage in repetitive work (Hunsicker, 1974; McCloy & Young, 1954).

In summary, muscular strength and endurance is often measured by performing a calisthenic exercise repeatedly, either within a time limit or to exhaustion. Push-ups, chin-ups, and dips are examples of the exercises used in muscular strength and endurance testing. Muscular strength and endurance of large muscle groups reflects the ability of individuals to perform vigorous work.

Abdominal Strength and Endurance

Of the large muscle groups in the body, much emphasis has been placed on the development of a strong abdominal musculature (ACSM, 1991; AAHPERD, 1980). For the recreational exercise enthusiast one of the main reasons to exercise the abdominals is the aesthetic appeal attained by having a flat, toned abdomen (Golding et al., 1989). Trainers and exercise leaders also know that strong trunk musculature,

including the abdominals, contributes to good posture and the avoidance of lower-back pain (Flint & Diehl, 1960; Petersen, Amundsen & Schendel, 1987).

The term trunk refers to the area of the body excluding the head and the extremities. However, in the literature the action, "flexing the trunk" is often substituted for the more accurate "flexing the spine". The terms "upper trunk" and "lower trunk" also appear in the literature, referring to the area of the trunk above and below the waist. The muscles of the anterior trunk are the abdominal muscle group, or more commonly, the abdominals. The abdominal muscle group is mainly composed of four large, flat muscles that protect the abdominal contents, and wrap around the lateral portion of the trunk. These muscles are arranged so that the fibers of the rectus abdominis run perpendicular to those of the transverse abdominis, and at an angle to the external and internal obliques. The fibers of the internal and external oblique run perpendicular to each other. This arrangement of criss-crossed fibers serves to protect and compress the internal organs from sternum and ribs to pelvic girdle. The abdominal muscles (except the transverse abdominis; its only action is compression of the abdomen) also act as antagonists to the back extensors to keep the trunk centered above the pelvic girdle and to keep it from tilting backward. The back extensor muscles, especially those that run parallel to the spine, keep the trunk from tilting forward and give us an erect posture. A balance between these muscles

is essential to keep the weight of the body centered over the pelvis (Petersen, Amundsen, & Schendel, 1987; Peterson & Wheeler, 1988). It has been well established that the abdominal muscles are important in maintaining good posture (Flint & Diehl, 1960; Peterson & Wheeler, 1988; Troup & Chapman, 1969). Good posture has been associated with the absence of lower-back pain, or more accurately, the lack of good posture has been related to the incidence of lower-back pain (Donchin et al., 1990; Langrana & Lee, 1984; Peterson & Wheeler, 1988; Rasch & Allman, 1972).

A balance of strength between the spine extensor and the spine flexor muscles has been shown to be a precursor of good posture. Posture photographs were taken for elementary school girls and the deviations from a standardized model were correlated with back and abdominal strength. The results indicated that trunk alignment and trunk strength balance were significantly correlated, allowing for the inference that a balance between the trunk muscles was strongly associated with antero-posterior alignment of the trunk (Flint & Diehl, 1960).

Troup and Chapman (1969) studied the trunk musculature (hip flexion/ extension and spine flexion/ extension) of 230 healthy, active individuals. They measured the static (isometric) strength of the muscle groups in an effort to establish a healthy ratio among them. Their findings show that a desirable ratio of trunk

flexors to extensors was around .75 (flexors/extensors). Their results concurred with previous results reported by Clarke (1966).

Other researchers have also found that the spine extensor group tends to be stronger than the spine flexor group. Hasue, Fujiwara, and Kikuchi (1980) used the Cybex isokinetic machine to study abdominal and back muscle strength in apparently healthy individuals (N=100). The reported ratio of abdominal strength to back strength was less than 1 (abdominal/back), indicating that abdominal muscles were weaker than back muscles. They also reported a significant correlation between the the isokinetic strength of abdominal and back muscles, indicating that stronger individuals show more strength in both groups of muscles, without a change in the ratio. Other results indicated that both abdominal and back muscle strength decreased with age, and that abdominal muscle strength may deteriorate more rapidly than back muscle strength. Correlations between the isokinetic method and isometric measures were reported to be high (Hasue et al., 1980).

In an effort to identify individuals at higher risk of low-back injury, Langrana and Lee (1984) also used the Cybex machine to study the isokinetic strength of the trunk musculature in industrial workers (N=121). Low abdominal and back strength or a low ratio of abdominal to back strength were both defined as indicators of an individual's proneness to back injury. The reported mean ratio of spine flexors and

extensors in "normal" subjects was .63 (flexor/extensor). They also found a significant drop in abdominal strength, but not in back strength, from the 25-30 age group to the 31-35 age group. Twenty-one individuals showed strength below the 95% confidence interval of the distributions for spine flexor strength and spine extensor strength, and were labeled as possessing "poor strength."

The importance of a balanced trunk musculature and a desirable ratio of spine flexors to extensors in the industrial setting goes beyond maintaining good posture. The trunk itself represents 50% of the body's mass. When a load is lifted, an added strain is placed on the flexor/extensor balance. The abdominal muscles have been found to increase the intra-thoracic and intra-abdominal pressure when a load is lifted, thereby relieving some of the stress placed on the trunk extensors (Petersen et al., 1987). Gracovetsky, Farfan, and Helleur (1985) constructed a mathematical model of the abdominal mechanism under stress. They concluded that the abdominal muscles control the shape and tonus of the lumbodorsal fascia, to which they attach, and thereby reduce stress placed on the fascia by the pull of the back extensors when lifting a load.

Helewa and colleagues (1990) validated the premise that lower-back pain sufferers have a weaker abdominal musculature than healthy individuals. They compared 12 back-pain sufferers and 12 non-back-pain sufferers on 2 measures of

abdominal strength, a sit-up test, and expiratory force. Abdominal strength was assessed by applying force against a manometer placed on the subject's sternum. The subject resisted the pressure while in isometric spine flexion, until the isometric contraction could no longer be held. In the second test of abdominal strength, the subject lay supine with the hips at right angles and the legs supported on a bench. The subject flexed the spine and, using both hands, applied as much force as possible to a manometer placed against the knees. The authors found statistically significant differences between the two groups in the tests of abdominal strength and in the sit-up test. The no-back pain group scored 31-45% better on all the tests.

If healthy individuals have better abdominal strength than back-pain sufferers, and a larger spine flexor/extensor ratio, then it would be tempting to assume that athletes would possess an even better abdominal musculature and a spine flexor/extensor ratio closer to 1 (Andersson, Sward, & Thorstensson, 1988). Andersson and colleagues (1988) studied the trunk muscle isokinetic and isometric strength in four groups of athletes (gymnasts, wrestlers, soccer players, and tennis players) and a group of non-athletes. In spine flexion, wrestlers, gymnasts and tennis players were significantly stronger than non-athletes. In spine extension, however, the athletes did not differ from non-athletes. Soccer players did not differ from non-athletes in spine flexion, presumably because soccer training does not include much

"pure trunk training." All the athlete groups had a higher flexor/extensor ratio than the non-athletes (athletes flexor/extensor ratio .49-.65; non-athletes ratio .45). Since the spine extensor tests did not differentiate athletes from non-athletes, it was concluded by the authors that the ratio differences were due to stronger spine flexors in athletes. Athletes also showed stronger values for their non-dominant sides on a lateral flexion test. From the results in this study, it appeared that training of the trunk muscles required to participate in a selected sport serves to attain a better balance of the musculature of the trunk (Andersson et al., 1988).

The claim that gains in muscle strength result in gains in muscular endurance has been specifically tested in the abdominal musculature. By training a specific muscle group for purposes of increasing the muscle's capacity to produce work, it is expected that the muscle's capacity to perform prolonged work will also improve (Anderson & Kearney, 1981; Johnson & Nelson, 1986; Knapik, 1989; Mathews, 1973; Smidt, Blanpied, & White, 1989). Smidt and colleagues (1989) found that endurance of the trunk musculature was retained or improved when gains in strength had been determined. The study also showed that even when subjects trained exclusively for strength, variables which reflected muscular strength and endurance of the trunk were retained (measured by an isokinetic device KIN/COM trunk testing unit).

In summary, abdominal strength and endurance is desirable from an aesthetic point of view, as well as beneficial to posture and lower back health. The spine extensor muscles are usually slightly stronger than the spine flexors, and a healthy ratio must be maintained between the two groups to avoid low-back dysfunction. Since spine flexors are often weaker than spine extensors, great emphasis has been placed by fitness leaders on strengthening the abdominal musculature.

Sit-up Exercises: Variations

Between the years of 1880-1900 physical education became a part of the formal educational program. Hitchcock set out to measure the physical characteristics and capabilities of young Americans attending the public schools. Since most measurements were taken in the school setting or in the military, mass testing was a consideration. It was for that reason that calisthenic type (i.e., using the body as resistance) exercises and tests were preferred to those requiring equipment (Clarke, 1976; Massey, 1970).

To develop muscular strength and endurance, exercising a muscle group against a certain resistance is necessary (ACSM, 1991; DeLorme, 1951; Johnson & Nelson, 1986; Mathews, 1973; McCloy & Young, 1954). Some examples of exercises used to strengthen the abdominal musculature are leg-lifts, basket hang, side lying trunk raise, V-sit, and sit-ups (Clarke, 1976; Flint, 1965). Leg-lifts and basket hangs use mainly

the hip flexor muscles and their use as an abdominal exercise is questionable (Flint, 1964; Sodeberg, 1966; Walters & Partridge, 1956), however the abdominals must remain in isometric contraction throughout their performance to keep the pelvis from tilting forward. Weak abdominals may prevent the performance of these exercises, and therefore the exercises do tend to increase abdominal strength and endurance (Sodeberg, 1966).

The sit-up is a popular exercise included in exercise programs to acquire and maintain abdominal strength and endurance (Golding et al., 1989). As the abdominal muscle group is contracted while laying supine, the trunk is raised against the pull of gravity. In the case of full sit-ups, the hip flexor muscle group aids the abdominal muscles to attain an upright position (Bender & Shea, 1964; Sodeberg, 1966). The weight of the trunk, arms, and head provides the resistance necessary to tax the spine flexor and hip flexor musculature (Bender & Shea, 1964; Fleishman, 1964).

The sit-up is usually performed repetitively, either at a given cadence or as fast as possible until exhaustion. It has been classified as a light exercise, raising heart rate only slightly above normal resting rate (10-20 BPM), and with an oxygen cost similar to that of very light walking (Ricci, Marchetti, & Figura, 1981). A reported record for maximum number of sit-ups performed in one set was over 5,000 as early as 1944 (Havlicek, 1944).

Terminology refering to sit-up exercises can be somewhat confusing. For purposes of clarifying the reported literature, the following definitions are offered:

-Sit-up is a general term describing any exercise that involves flexing the spine, the hips, or both the spine and the hips, from a supine position.

-Full sit-up involves flexing both the spine and the hips.

-Curl-up is a term which describes the practice of flexing the neck, the spine, then the hips, with emphasis on keeping the spine rounded throughout an exercise. Bender and Shea (1964) best described this practice by instructing subjects to "...raise the head by bending the neck. Continue bending the trunk forward attempting to lift one vertebra at a time off the floor." The term "curl" has been erroneously used to refer to "partial curl", however curl-ups can be full curl-ups or partial curl-ups.

-Half sit-up is synonymous with abdominal crunch, partial sit-up, and partial curl-up. This exercise involves only flexion of the spine, usually until the inferior angles of the scapulae leave the exercise surface.

The sit-up exercise is popular among physical educators because it requires no equipment, and the weight of the trunk is enough to provide the resistance necessary to tax the abdominal muscle group in most individuals (Barrow & McGee, 1971). Generally, sit-up exercises are performed by flexing the spine while lying supine. As many as 52 variations of the sit-up exercise have been reported in the literature

(Clarke, 1976); some of the most common are described below and illustrated in Appendix A.

1. *Conventional full sit-up.* From the supine position, the knees are extended and the hips are flexed to a vertical position. The arms can be held across the chest, or the hands can be clasped behind the head. Feet can be supported or not supported, either mechanically (e.g., by a strap, a bar, a bench, etc.), or held by a partner.

2. *Conventional hook lying full sit-up.* From the supine position, the knees are flexed at approximately 65° and the spine and hips are flexed to a vertical position. The feet can be supported ar not supported and the hands are either held clasped behind the head, held across the chest, or extended by the sides. The purpose of bending the knees is to eliminate some of the action of the hip flexors, thus relying more on the abdominals to initiate the sit-up motion.

3. *Modified hook full sit-up.* Performed as the conventional hook lying full sit-up except the legs are placed on a bench and thus the hips and the knees remain flexed approximately 90° throughout the exercise. This practice further eliminates the action of the hip flexors.

4. *Incline full sit-up.* To increase the resistance of performing the sit-up against the pull of gravity, this exercise is performed in the same manner as the conventional or the hook lying full sit-ups, except the subject lies on an incline bench with the legs

higher than the head. It is usually performed with the feet supported to avoid sliding off the bench.

5. V-sit. From a supine position, the legs (knees extended) are flexed at the hip and the trunk is flexed at the waist simultaneously forming a "V" position. The arms are held in front of the subject for balance throughout the exercise and the supine position is regained with each repetition (Flint, 1965; Gutin & Lipetz, 1969). The exercise can be performed isometrically by holding the "V" position for a length of time, or isotonically by repeating the sequence from supine to "V" and back to supine.

6. Full Curl-up. From the supine position, the trunk is flexed emphasizing a curled back by flexing the head first and keeping the chin to the chest throughout the exercise. The curl-up can be performed with the legs extended or bent at the knees and the arms extended by the sides, clasped behind the head, or crossed over the chest. One of the current standardized tests of abdominal strength and endurance utilizes the full curl-up, with the legs bent at approximately right angles and the feet supported. The subject touches opposite elbow to opposite knee with each curl-up and returns the shoulders to the mat (Golding et al., 1989).

Electromyographic studies have shown that, in addition to the abdominal muscle group, the above exercises recruit the hip flexor muscle group (Flint, 1965; Godfrey et al., 1977; Gutin & Lipetz, 1969;). These studies have shown that better

isolation of the abdominal muscle group is obtained when partial curl-ups or half sit-ups are employed. Described generally, a partial curl-up or half sit-up is characterized by the curling action of the upper spine, and the absence of hip flexion. Thus, the subject's scapulae lift from the exercise surface to approximately 30° to 45°, but the lower trunk does not. The most common variations of these exercises follow:

7. Conventional partial curl-up (or half sit-up). From the supine position with the knees extended, the subject flexes the upper spine by flexing the neck, keeping the chin to the chest and the back rounded throughout the exercise. The arms can be placed behind the head with hands clasped, crossed over the chest, or extended to the sides.

8. Hook-lying partial curl-up. From the supine position, but with the knees bent at approximately 65° to 90°, the exercise is performed in the same manner as the conventional curl-up. Both exercises can be performed with the feet supported or not supported.

9. Partial curl-up with trunk twist. This exercise is performed in the same manner as same as the hook-lying partial curl-up, except the trunk is rotated at the apex of the curl-up. This practice exercises the external and internal obliques to a greater extent than straight partial curls. Feet can be supported or not supported.

10. Modified hook-lying partial curl-up. From the supine position, as for the hook-lying partial curl-up, the knees are bent and are placed on a bench. The upper trunk flexes in a curl-up as for other curls and the hips and the knees remain bent at approximately right angles. The hands can be placed behind the head or neck, or crossed over the chest (Flint, 1965; Godfrey et al., 1977; Gutin & Lipetz, 1969).

In summary, there are several variations of sit-up exercises in existence. Flexing the knees eliminates some of the action of the hip flexor muscle group by placing this group at a mechanical disadvantage. Further, the action of the abdominal muscle group is better isolated by performing partial curls. A more precise kinesiological analysis of full sit-ups and half sit-ups is discussed in the next section.

Kinesiology and Biomechanics of Sit-ups

Although sit-ups are commonly thought of as abdominal exercises, some variations also require hip flexion. The three abdominal muscles involved in flexion of the spine are, the rectus abdominis, the external obliques, and the internal obliques. These muscles do not cross the hip joint but traverse the abdominal area from pelvis to rib cage. The rectus abdominis attaches to the sternum and to the pubic symphysis, therefore its only possible action is flexion of the spine. The obliques produce lateral flexion and rotation of the spine when contracted independently, and flexion of the spine when contracted simultaneously (DeLacerda, 1978; Gray, 1977). The two hip

flexors most involved in abdominal exercises are the iliopsoas and the rectus femoris, although other hip flexors (gracilis, sartorius, and the adductor group) have been found to be involved (Ricci et al., 1981). The iliopsoas is a combination of three muscles (iliacus, psoas major, and psoas minor), however the fibers of these three muscles merge and do not have independent actions. It is therefore common to refer to the group as the iliopsoas. These muscles cross the hip joint attaching the pelvis to the femur, therefore their action consists of flexing the legs toward the trunk or the trunk toward the legs (Clarke, 1976; DeLacerda, 1978; Gray, 1977).

The complete sequence of a typical sit-up exercise is shown in Figure 4. A sit-up exercise is performed from a supine position by isometrically contracting the abdominals first, thereby anteriorly tilting and stabilizing the pelvis, pulling the lower back toward the exercise surface, and preventing excessive lordosis (DeLacerda, 1978; Le Veau, 1973; Peterson & Wheeler, 1988; Sodeberg, 1966). The spinal flexion is completed and the hip flexors come into play when the spine is flexed approximately 30° to 45° from the exercise surface. The trunk is then raised to an upright position (90°) (Clarke, 1976; DeLacerda, 1978; Flint, 1965; Gutin & Lipetz, 1971). The two muscle groups concentrically contract to lift the trunk from the exercise surface, and eccentrically contract to lower the trunk and return to a supine position.

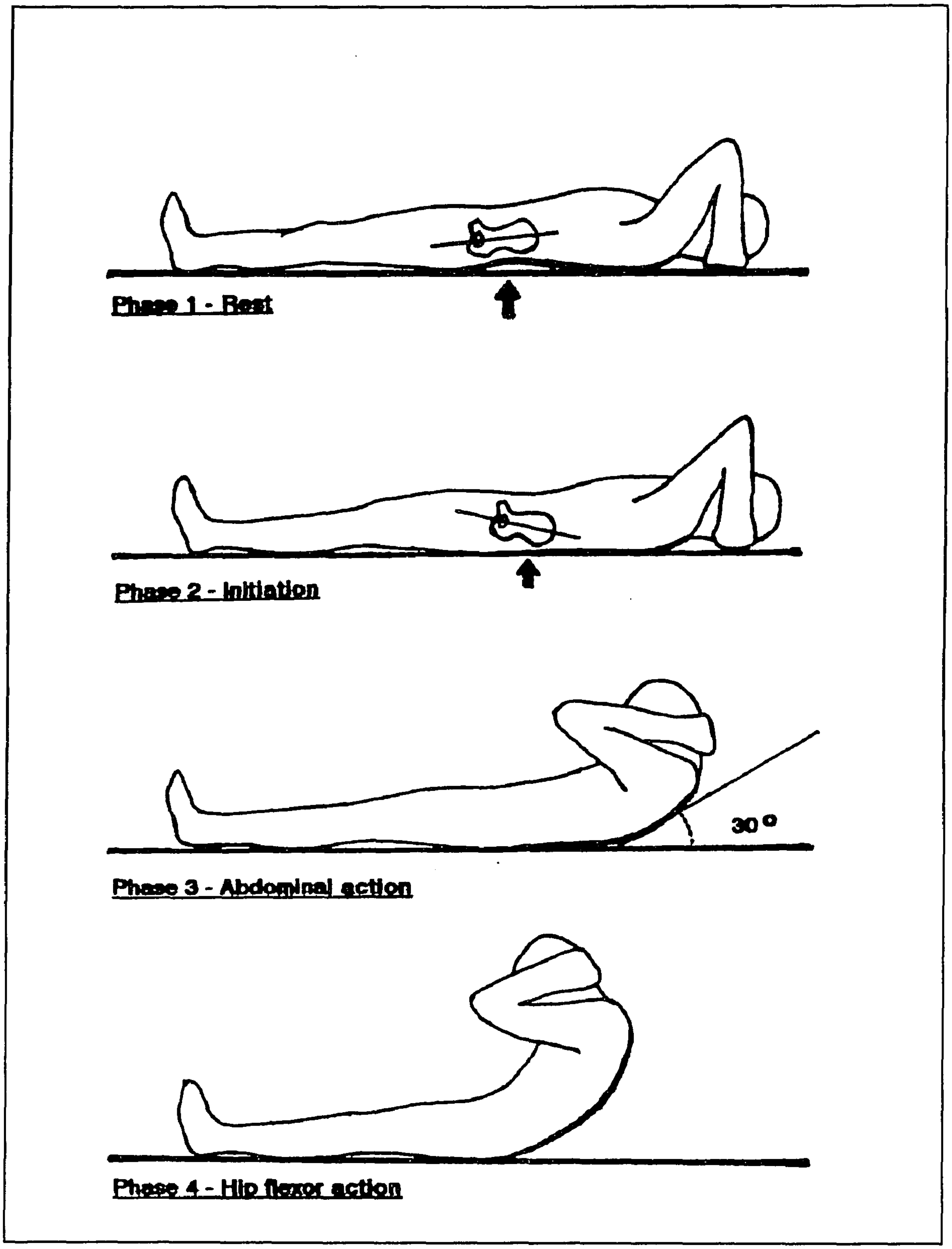


Figure 4 - Correct performance of a sit-up exercise

The neck is flexed throughout the exercise; failure to do so causes an uncomfortable stiffness of the neck extensors, and may increase lordosis (Sodeberg, 1966). The arms can be held across the chest, crossed behind the head, or held extended by the sides of the body. Some discomfort was reported by subjects when the arms were held by the sides of the body, however, subjects who had practiced the exercise in that manner reported no discomfort (Diener & Golding, 1991).

A common error committed when performing sit-ups is to flex the hips initially without flexing the head or the spine. In this case, the hip flexors are responsible for the action, and the abdominals act as stabilizers on the pelvis to prevent it from tilting anteriorly, and on the spine to prevent it from hyper-extending. If the abdominals are weak, this practice can result in increased lumbar curve, and in some cases, complete failure to perform a sit-up (DeLacerda, 1978; Ricci et al., 1981; Sodeberg, 1966). The degree of involvement of the hip flexors depends on whether the exercise being performed is a full sit-up or a half sit-up, and on the position of the legs. Generally, sit-ups performed with the knees extended recruit the hip flexors upon initiation of the sit-up, and again after the trunk has been lifted 30° to 45°. Bent knees and hips tend to inhibit the action of the hip flexors (Clarke, 1976; DeLacerda, 1978). This point will be discussed in more detail in the review of electromyographic studies.

The biomechanics of the sit-up exercise were studied by Ricci and colleagues (1981), in four sit-up variations: the long-lying full sit-up, hook lying full sit-up, hook-lying with legs elevated, and partial curl-up (a half sit-up). Legs were stabilized at the knees and at the ankles. Their conclusions were as follows: 1) In all variations, the sit-up was preceded by a "hollowing" of the lumbar spine, a forward or anterior tilt of the pelvis, and a slight hyperextension of the upper spine. The "hollowing" of the lumbar spine was minimized in the partial curl-up. 2) At the initiation of the spine flexion, it was noted that the abdominal muscles were eccentrically contracted in response to the forward pelvic tilt. Concentric contraction was noted up to the point when the hip flexors start flexing the hips (30° to 45° of trunk lift), at which point the abdominals maintained isometric contraction. 3) The partial curl-up was said to cause a greater response from the abdominal muscle group between 170° and 130°. 4) The tested sit-up variations recruited the hip flexors, dorsiflexors, and plantar flexors. The partial curl-up did not recruit the leg muscle groups as much as the three full sit-up exercises.

In summary, sit-up exercises require flexion of the spine and flexion of the hips and recruit both spine and hip flexors. Half sit-ups or partial curls recruit the hip flexors to a much lesser extent, since their action stops short of the point at which these muscles are recruited (30° to 45° of spine flexion measured from exercise surface).

Recruitment of the muscles during an action can be determined by palpating the muscle groups involved during performance of the particular exercise. However, a much more accurate method is to record the electrical activity in the muscles by using electromyography.

Electromyographic (EMG) Studies of Sit-up Exercises

An action potential initiates the contraction of the muscle cell. When a motor neuron delivers the appropriate neurotransmitter to the muscle cell, an electrical event is initiated and the muscle cell depolarizes. This electrical activity can be detected with the use of skin (surface) or wire (deep) electrodes, amplified, and recorded with an electromyograph (Clarke, 1976; Loeb & Gans, 1986). Exercise scientists use electromyography (EMG) to record specific muscle involvement in various activities, the percent of fibers recruited, and the duration of muscle contractions (Loeb & Gans, 1986). Researchers have used EMG studies extensively to investigate the electrical activity of the spine and hip flexor muscle groups while performing sit-up exercises. EMG studies have been the bases for the face validity of some sit-up tests, and the logistics behind sit-up exercise variations and tests (Clarke, 1976; Flint, 1965; McCloy & Young, 1954).

In spite of the apparent physiological reliability of EMG studies to investigate muscle involvement, controversy exists among researchers regarding the degree of

involvement of muscle groups (namely the hip flexors) during variations in sit-up exercises (Clarke, 1976; Flint, 1965; Godfrey et al, 1977). These discrepancies may be due to factors affecting EMG recordings, and to the methodologies used in different studies (Loeb & Gans, 1986; O'Connell & Gardner, 1962). Before launching into a review of the EMG literature pertinent to sit-up studies, the following points are outlined with the purpose of explaining those discrepancies.

A thorough kinesiological analysis of a movement must precede an EMG study in order to determine electrode type, depth of placement, and site of location. In addition to identifying the specific muscles responsible for the action, the activities of the antagonist and stabilizing muscle groups must also be recorded during an EMG study (O'Connell & Gardner, 1962). In the case of sit-ups, the stabilization of the feet or the legs may greatly affect the recorded activity of the hip flexors and even the knee flexors and plantar or dorsi flexors. The interpretation of the recorded activity may differ from study to study.

Regarding the methodology of EMG studies, Loeb and Gans (1986) warn that researchers sometimes may "...do what everyone else has been doing." In the case of sit-up studies, if the methodology of two studies is identical, they may yield the same results; if it is not, the results may differ. Additional caution must be taken in interpreting results when the weight of the participant's body, rather than a fixed

weight, is used as resistance during an EMG study. Anthropometric differences in the bodies of participants may cause the resistance to vary in weight and size, and the muscular activity required to produce force against that resistance to differ (Loeb & Gans, 1986; O'Connell & Gardner, 1962). In the case of sit-ups, a slight bias to one side of the body or the other while performing repeated movements may cause different EMG readings in the muscle groups involved, as may differences in the upper body weight and anthropometry of the subjects. Heavier trunks or wider shoulders may affect the degree of involvement of stabilizing muscles as well as the effort exerted by the agonists. Lastly, interpretation of the recordings is somewhat subjective, therefore studies in which the actual EMG tracings are not presented rely solely on the author's readings of the tracings and hence his or her conclusions.

One of the earlier EMG studies in sit-up research is also one of the most complete. Walters and Partridge (1956) studied EMG activity of the abdominal muscles and the rectus femoris in 11 variations of abdominal exercises, including full sit-ups and partial curls. Two female subjects performed the exercises to complete a total of over 3,000 EMG observations. Conclusions of the study were:

- Hip flexor (rectus femoris) activity was minimized when the knees were at 65° and the feet were not held. When the hip flexor activity was minimized, the abdominal group activity was increased.

- Regarding the upper and lower portions of the rectus abdominis, the end of the muscle farthest away from the resistance showed the most activity.
- Out of the exercises tested, the full curl-up, partial curl-up, and the "V"-sit were the most effective exercises for the abdominal musculature.
- Leg circling elicited mainly the external obliques, whereas trunk rotation and tilting of the pelvis was mainly due to internal oblique activity.

Some of the conclusions reached by Walters and Partridge (1956) were supported by a later study. Flint (1964) studied the EMG activity of the upper and lower rectus abdominis and the external obliques of 10 female subjects, during 10 variations of the sit-up exercise. All variations involved either full sit-ups or full curl-ups, with the knees extended or flexed at 45°, the feet supported or not supported, and an added trunk twist. Subjects were filmed so that physical activity and EMG activity could be synchronized. The findings include:

- The lower rectus abdominis showed more activity than the upper rectus, when the feet were supported, and during the 60° to 90° phase of the sit-ups. This conclusion supports findings of Walters and Partridge (1956) who found that the end of the muscle farthest away from the resistance (in this case the upper trunk) showed the most activity.

- The three abdominal muscles studied showed most activity during the action phase from the supine position to 45° of spine flexion, decreasing as the hips were flexed aand the trunk was lifted to an upright position.

- In descending order of preference, the most recommended exercises for the abdominals were: 1) The full curl-up, knees at 45°, with trunk twist. 2) Same exercise without trunk twist but with feet supported. 3) Full sit-up, knees flexed at 45°, feet supported. The full curl-up was also chosen by Walters and Partridge (1956) as eliciting the most abdominal activity.

Since the iliopsoas is a strong hip flexor, the activity of this muscle has been studied in an effort to investigate the muscle's contribution to the sit-up exercise. LaBan, Raptou, and Johnsons (1965) studied the EMG function of the iliopsoas muscle in five subjects during sit-ups and other activities (walking and standing), using wire electrodes inserted near the insertion of the muscle. The iliopsoas showed activity throughout the entire range of the full sit-up when the knees were bent. When the knees were extended, activity began after the trunk was lifted 30° from the exercise surface, presumably by the abdominals. The authors do not specify whether the full sit-up was performed by curling the spine, or exclusively by flexing the hips.

In another study, Flint (1965) studied the comparative EMG activity of the iliopsoas and the rectus abdominis muscles in full sit-ups, full curl-ups, side-lying trunk

raises, and straight leg raises. A film recording was used to simultaneously record the physical activity. Conclusions of the study include:

- The rectus abdominis is the primary mover for the initial phase (up to 45° trunk lift) of sit-ups and curl-ups. This finding agrees with those of Walters and Partridge (1956), and supports the conclusions of LaBan and colleagues (1965).
- Positioning of the feet affected abdominal muscle activity for all variations of sit-ups but not iliopsoas activity. This finding contradicts that of LaBan and colleagues (1965) who stated that iliopsoas activity was limited when the knees were extended during the initiation phase of the sit-up. Less abdominal muscle activity was detected when the feet were supported.
- The abdominal muscles were involved to a greater extent when the feet were not supported and the knees were flexed. The iliopsoas was most involved when the legs were extended and the feet were supported. This finding agrees with those of the previous literature.

The activity of the rectus abdominis muscle was investigated by Gutin and Lipetz (1969) in 11 abdominal exercises. The basket hang (really a hip flexor exercise) was found to elicit the greatest effort from the rectus abdominis, followed by the hook full sit-up, inclined full sit-up and full curl-up, conventional sit-up, and V-sit. All exercises except the V-sit elicited more effort than an isometric trunk flexion test. The

authors concluded that when the pelvis is not supported, as in the basket hang, the rectus abdominis must remain in isometric contraction to prevent the spine from hyper-extending. The basket hang exercise elicited more isometric activity than sit-up exercises due to the fact that they are performed in a supine position, and the pelvis is usually partially supported by the exercise surface.

In addition to recording the activity of a muscle during a particular exercise, EMG recordings can also be used to record the duration of that activity. The duration of activity in the external oblique, rectus femoris, and rectus abdominis muscles was studied using eight sit-up variations by Godfrey and colleagues, (1977). They also explored the effects of cadence (fast and slow), and feet supported or not supported, on muscular activity. Greater activity was recorded for fast cadences in all forms of the sit-ups. Rectus abdominis and external oblique activity was greater during initial phase of the sit-up (head and scapulae lifted), whereas the rectus femoris was more active during the hip flexion phase. Supporting the feet in the hook lying position increased the duration of abdominal muscle activity and rectus femoris activity. A fast cadence elicited more activity from all the muscles even when the feet were supported. No significant differences were found for rectus abdominis activity when the feet were supported in the long lying position, versus not supported in the hook lying position.

The hook lying, unsupported position was found to be superior in eliciting all abdominal muscle activity and reducing rectus femoris activity. This finding is consistent throughout the literature.

Further support for earlier studies was given by Halpern and Bleck (1979) who also offered a criteria for determining the maximum degree of spine flexion needed to fully elicit abdominal muscle activity. The study investigated EMG activity of the abdominal muscle group in four variations of full sit-ups and a half sit-up. The half sit-up, performed with the knees flexed and lifting only the scapulae from the surface was said to result in much greater abdominal activity than the full sit-up exercises. The rectus abdominis muscle was found to be active 34% of the duration of the full sit-up cycle, compared to 90% of the half sit-up cycle. The authors also investigated the lumbar angle displacement (L1 to L5). The half sit-up displaced the lumbar spine only 3° from the resting state, whereas the full sit-ups required as much as a 38° displacement. The half sit-up, performed by flexing the spine to the point where the inferior angles of the scapulae were lifted off the exercise surface, was deemed to be safer and more effective for abdominal muscle activity.

In summary, most researchers agree that the function of the rectus abdominis is greater during the initial and completion phases of the full sit-up, and during the performance of half sit-ups. Hip flexor (rectus femoris, iliopsoas) activity is minimized

by flexing the knees and the hips, and when the feet are not supported, although some controversy exists regarding the activity of the iliopsoas. Abdominal muscle activity is also elicited when the pelvis is not stabilized, as in the basket hang. The external and internal obliques are best exercised in sit-up variations which include a twist of the trunk. Finally, in terms of safety of the lumbar spine, the half sit-up exercise is better than the full sit-up.

Contra-indications To Full Sit-ups

Two main concerns about the performance of full sit-ups have emerged throughout the years. One concerns the development of an excessive lumbar curve (lordosis) due to the strengthening and tightening of the hip flexors (mostly the iliopsoas), said to be evident in athletes (Allsop, 1971; Flint, 1964; Rasch & Allman, 1972). The other refers to the actual practice of the full sit-up exercise by the general population, and possible damage to the lumbar spine when the abdominal muscles cannot overcome the pull of the hip flexors (Donchin et al., 1990; Flint, 1965; Sodeberg, 1966).

Nelson (1964) criticized the use of full sit-ups as a beginner exercise. In a kinesiological analysis of the full sit-up exercise, he noted that when an individual's abdominal musculature is too weak to stabilize the pelvis, the action of the hip flexors will hyper-extend the lumbar spine. In a normal individual the ratio of hip flexors to

abdominals can be 2:1 to 3:1 (Clarke, 1976), thus the abdominals are at a great disadvantage when initiating the sit-up. The author suggested that weaker individuals should start strengthening the abdominal musculature by performing head raises and half sit-ups, before attempting the more difficult and demanding full sit-up exercises.

Flint (1964) evaluated several exercises and their possible dangers to performers. She stated that the main muscles used in performing the full sit-up with the legs extended and the feet stabilized were the hip flexors, not the abdominals. Further, she cautioned that an imbalance between the hip flexors and the "trunk" (spine) flexors would cause an anterior tilt of the pelvis and an exaggerated lumbar curve. Performing this exercise would only strengthen the hip flexors, thus accentuating the imbalance. The author recommended the V-sit and the full curl-up with the knees flexed as abdominal strengthening exercises.

The kinesiological basis for avoiding the performance of full sit-ups in the presence of weak abdominals was demonstrated by Logan (1965), who reported a phenomenon called the "psoas paradox". The psoas paradox refers to the dual action performed by this muscle under specific circumstances. It briefly states that when the abdominals fail to stabilize the pelvis and the iliopsoas (usually a spine and hip flexor) is contracted, the spine is hyper-extended. More specifically, this stress occurs when the initial phase of the sit-up is attempted. The iliopsoas, a hip flexor and lumbar

spine flexor, can under some circumstances hyper-extend the lumbar spine. When in a supine position, during the initial phase of the sit-up, contraction of the iliopsoas can overpower weak abdominal muscles, resulting in hyperextension of the lumbar vertebrae (Logan, 1965; Rasch & Burke, 1974).

Criticism of the sit-up exercise extended to the use of the full sit-up in physical fitness testing batteries. Kendall (1965) reported a criticism of current exercises, among them the full sit-up. She discusses the validity of the full sit-up exercise and of the full sit-up test as a measurement of abdominal strength and endurance. Her discussion argues that whether the sit-up is performed with the knees extended or flexed, the hip flexors are recruited, and that weaker individuals can perform a full sit-up by using the hip flexors. In addition, Kendall warns that the second phase of the sit-up (after 30° to 45° of spine flexion), is still entirely a hip flexor exercise. Regarding the use of the full sit-up as a test, Kendall argues that, when the feet are held by the experimenter, individuals with weaker abdominal musculature can easily "obscure" their weakness by flexing the hips. In the latter case, the abdominals are minimally contracted to prevent hyperextension of the spine, however an increased lumbar curve is evident. Individuals with poor spine flexibility who are unable to curl their trunk are also at a disadvantage when initiating the sit-up, since spine flexion is hindered and hip flexion has to initiate the sit-up motion (Kendall, 1965).

Sodeberg (1966) cautioned against performing sit-ups with the knees extended and the feet supported for the same reason. He also warned that the lumbar curve (lordosis) was increased when the full sit-up was performed without an initial curling of the neck and spine. Lastly, it was mentioned that, in a testing situation, an individual could overcome weak abdominals by using the hip flexors to achieve a sit-up if the feet were supported. Thus abdominal strength and endurance could be "faked" by a subject under pressure to perform, such as the case of mass testing (Sodeberg, 1966).

Allsop (1971) examined the possible hazards of abdominal exercises, specifically regarding the action of the iliopsoas. The author defined the long lying full sit-up performed with the feet held down, as an iliopsoas strengthening exercise, not an abdominal exercise. He noted that supporting the feet served to essentially stabilize the insertion of the iliopsoas muscle, thus giving the muscle a greater mechanical advantage. Allsop reported that in 20 commonly used physical fitness test batteries, 17 used the full sit-up test with legs extended and the feet stabilized. The AAHPER and the President's Council on Physical Fitness and Sports were among them.

Rasch and Allman (1972) investigated several controversial exercises, among them, the full sit-up and the leg lift, in an effort to eliminate dangerous practices in school physical fitness education. Their argument also concerned the activity of the

iliopsoas during the straight leg sit-up, noting that the repeated practice of full sit-ups may strengthen the iliopsoas, do little for the abdominals, and increase the lordotic curve to the point where injury occurs. The caution was extended to body builders, who must do thousands of sit-ups to obtain definition, and to women, who start out with a weaker abdominal musculature than men. The authors advise the use of a bent knee full curl-up to exercise the abdominals, and emphasize that from about one-third of the way to a sitting position the action is mainly due to the hip flexors.

LeVeau (1973) used X-rays to study the changes which occur in the lumbar spine when an individual performs variations of sit-ups. Findings of his study include a significant increase in the angle between L5 and S1 when sit-ups were performed in the straight leg position versus the bent knee position. The straight-leg full sit-up was also found to displace L5 anteriorly with respect to the sacrum and to increase disc compression. The bent knee sit-up decreased sacral angle, lordosis angle, and intervertebral angle (L1-L5), when compared with the straight leg sit-up. An increase in the angle between L5 and S1 was even found in a resting straight leg position as compared with a resting bent leg position.

Gilliam (1976) criticized the use of straight leg sit-ups and leg lifts as exercises and tests used to assess the abdominal musculature. He reported that the primary agonists of such exercises are the hip flexors, and repeated performance of the exercises

would serve to strengthen them, not the abdominals. When the hip flexors become stronger without corresponding gains in abdominal strength, the lumbar curve is increased with the possibility of resulting in lower back pain. The author recommends that abdominal exercises be performed with the knees bent, and a curling motion "...starting with the head, followed by the spine."

Plowman and Falls (1978) published a revision of the AAHPER Youth Fitness Test, in which several exercises were revised. The rationale given for revision of the full sit-up concerned individuals with weak abdominal musculature. Weak abdominals were said to allow the pelvis to tilt anteriorly and produce an "abnormal" arch in the lower back. Among the implications of low-back dysfunction, it was reported that 16% of the population had low-back pain syndrome, and that as much as 80% of the population had a "simple but significant backache." The timed bent-knee full sit-up test was deemed "marginally acceptable", due to lack of validity or feasibility of any other existing test of abdominal strength and endurance.

Performance of partial curls without recruitment of the hip flexor muscle group was demonstrated to be possible by Ash and Burnett (1989). They report a case study of a paraplegic (below L1) individual, who was able to perform a partial curl-up to 45° of spine flexion, without the aid of hip flexors, and without apparent lumbar strain. Since the individual had non-functional hip flexors, they concluded that the partial

curl-up could be performed without recruiting the hip flexor muscle group. The authors recommend the partial curl-up as an applicable exercise for low-back rehabilitation programs, when increasing abdominal strength is desired.

In summary, when full sit-ups are performed with the feet stabilized and the legs extended, they can increase the strain placed in the lumbar vertebrae and increase lordosis. Both of these events can be detrimental to the lower back and result in chronic low-back pain (Peterson & Wheeler, 1988). This danger is increased when individuals possess weak abdominal musculature. The straight body sit-up is not recommended, as its initiation requires that the lumbar curve be increased to stabilize the pelvis. The curl-up is preferred, initiating the action by flexing the cervical spine and the thoracic spine; the lumbar spine should remain on the exercise surface. The partial curl-up is deemed the safest of the abdominal exercises. Based on these conclusions abdominal strength and endurance tests should also use the preferred variations of partial curls, and abandon the use of full sit-ups.

Sit-up Tests and Norms

Three factors will be emphasized throughout the review of existing sit-up test protocols: 1) the sit-up variation utilized, and the protocol itself (to exhaustion, timed, with assistance, etc.); 2) correlations, if reported, with other fitness tests and with alternate measures of strength and endurance; and, 3) criticisms of the protocol. The

majority of the standardized tests found in the literature use full sit-ups or full curl-ups, therefore the criticisms reviewed in the previous section apply to those protocols and will not be repeated.

DeWitt (1944) investigated three sit-up test protocols intending to validate the sit-up type test with isometric abdominal strength and endurance. Strength was measured by isometrically contracting the abdominals against a dynamometer and recording the maximum pull. Abdominal endurance was defined as the length of time a subject was able to keep the trunk off the floor, while maintaining spine flexion (45°). Both tests were performed with the feet stabilized at the ankles. The sit-up tests used the full sit-up with trunk twist, and the same with the feet stabilized. In the first test, the subject performed the sit-up with the hands clasped behind the head and the knees extended, touched opposite elbow to opposite knee, and returned the shoulders to the exercise surface. The test ended when the subject could not perform another sit-up, or when the subject paused. The second test protocol was identical except an experimenter stabilized the ankles. The third protocol was identical to the second, except a 2-minute time limit was imposed. The correlations of the three sit-up tests with abdominal strength were .040, .157, and .142, respectively. The correlations of the three tests with abdominal endurance were, .245, .370, and .257. The author concluded that "...there is a definite question as to the justification for calling the (full)

sit-up type test a test of strength and endurance of the abdominal muscles (DeWitt, 1944)."

Havlicek (1944) criticized unlimited time tests due to the length of their administration, and because once the 100th percentile score had been reached by subjects, evaluation of their performance was truncated. The 1-minute, 2-minute, 3-minute, and 5-minute full sit-up tests were evaluated for practicality of administration and performance discriminating power. The full sit-up with legs extended and feet stabilized was utilized. Subjects (Air Force recruits) held the hands clasped behind the head and touched opposite elbow to opposite knee. The three-minute test was deemed the most practical and discriminating because it did not allow enough time for setting a pace, and was long enough to discriminate between individual performance.

Wedemeyer (1946) studied the relationship of a 2-minute full sit-up test, an unlimited time full sit-up test, and sit-up strength using the Martin Breaking Strength method. The full sit-up tests used the conventional full sit-up with the knees extended and the feet stabilized. The first test was a 2-minute timed test; the second test did not use a time limit, but the cadence was set at 1 sit-up every 2 seconds. The Martin Breaking Strength method used a dynamometer to measure the point at which a subject could not resist the experimenter's pull, or "broke". A strap was attached to a dynamometer and to the subject's upper trunk directly below the axilla, and the

subject (feet stabilized) was made to flex the spine at 45° against the pull of the experimenter. The correlations between 2-minute sit-ups and unlimited sit-ups with strength were .615 and .471 respectively. The author concluded that there was no relationship between strength and the performance in the sit-up test, and that the full sit-up tests measured a combination of strength and endurance or the "general fitness" of the abdominal and hip flexor muscle groups.

Berger (1965) investigated the concurrent and face validity of the 2-minute full sit-up test, the unlimited time full sit-up test, and a 1-RM test of abdominal strength. The 1-RM test involved the performance of a full sit-up with an added load. The full sit-ups were performed with the knees at 90° and the feet stabilized. The up position of the sit-up was determined by the achievement of an "upright" position. The unlimited time sit-up test was performed to a set cadence of 20 sit-ups per minute. The correlations between the 2-minute full sit-up test, the unlimited time sit-up test and 1-RM test of strength were .508 and .518 respectively. The intercorrelation between the two forms of sit-up test was .712. The author concluded that the two full sit-up tests were similarly correlated with maximal isotonic abdominal strength, and that the 2-minute timed test was comparable to the unlimited time sit-up test as a test of strength and endurance of the abdominal muscles.

Harvey and Scott (1965) examined the relationship between the 30-second curl-down test, the 60-second curl-down test, and isometric abdominal strength. The curl-down is a variation of the full curl-up. Subjects were in a seated position, with the knees flexed, the feet stabilized, and the hands clasped behind the head. Subjects were instructed to "uncurl" just until the shoulders touched the ground, and then "curl" back up to the seated position. Isometric abdominal strength was measured by a dynamometer and a strength table. The correlations between the 30-second test, the 60-second test, and strength were .44 and .32 respectively. The correlation between the two versions of the curl-down test was .84. The number of curl-downs in the 60-second test was recorded at every 10 second interval. Visual inspection of the data prompted the authors to conclude that after the 40 second interval the scores dropped, presumably indicating fatigue, however statistical analyses supporting this statement were not reported. The authors concluded that the curl-down test should be limited to 40 seconds to better represent a test of strength, rather than endurance, of the abdominal musculature.

Vincent and Britten (1980) examined the reliability and validity of a curl-up test, in search of a substitute for the bent knee full sit-up test (1-minute). An abdominal exercise was proposed in which subjects raise only the upper back off an exercise mat (partial curl-up), with the feet not stabilized, and the knees bent at right

angles. This position is held for 4 seconds, the trunk is rotated to one side and held, and to the other side and held. The 12 second sequence is repeated and, as abdominal muscular endurance is developed, the length of time the positions are held can be increased. A partial curl-up test was also proposed, in which subjects held the curled position until exhaustion. A partner held a closed fist under the subject's fifth thoracic vertebra, and the instructor called out five second intervals. The test ended when the subject could not hold the position any longer and touched the partner's fist. Test-retest reliability on three different age groups (elementary school, junior high, and college) was reported to be "insufficiently high to be acceptable" (.53-.71). Concurrent validity was examined by correlating scores obtained with the new test protocol with the 1-minute bent knee protocol. The correlation coefficients were .27-.39 (not significant) for the three age groups tested. The authors concluded that the curl-up test was not a reliable measure of abdominal strength and endurance and not useful for mass testing in school settings due to the low reliability and validity.

Faulkner and Stewart (1982) criticized the use of a timed 1-minute full sit-up test protocol to assess the abdominal strength and endurance of the general population. Among their criticisms: 1) the performance of "all out" exercises is against the principles of sound and safe exercises for unfit individuals; 2) it may be detrimental to the motivation of an individual who has just begun an exercise program

to fail to perform sit-ups for the duration of the 1-minute test; and, 3) the test protocol mandates that the feet be stabilized, which has been shown to recruit the hip flexors. The authors proposed a protocol in which the full curl-up was used. Subjects would perform the full curl-up with the knees at right angles, the feet not stabilized, and the arms extended by the sides of the body. Scoring of the test is "pass-fail"; if the subject performs one curl-up with ease, abdominal strength is said to be sufficient; if the subject demonstrates difficulty, abdominal strength needs improvement; and, if the subject fails, abdominal strength is insufficient. The test is limited to the assessment of sedentary adults, that is, it is not useful for discriminating between levels of abdominal musculature fitness in the exercising population. The study's purpose did not include testing the reliability and validity of the test, and none was reported.

Jette, Sidney, and Cicutti (1984) proposed a partial curl-up protocol which was included in the Canadian Fitness Award program, and replaced the 1-minute timed full sit-up test. Subjects lie supine with the knees at 140°, the arms extended, and the hands held on the thighs. Subjects curl-up until the tips of the fingers touch the patella, at which point the upper trunk is raised approximately 30° from the exercise surface. The head returns to the surface on each repetition, and the subject performs to exhaustion or until a cadence of 20 curl-ups per minute using proper form cannot be maintained, or until subjects reach 100 curl-ups. Dickinson, Banister, Allen, and

Chapman, (1984) reported a test-retest reliability of .88. In a later study it was reported that subjects had trouble keeping the proper knee angle, and the soles of the feet on the ground (Faulkner et al., 1989).

Quinney, Smith, and Wenger (1984) proposed a full curl-up protocol for assessing abdominal strength and endurance in professional ice-hockey players. The full curl-up is performed with the knees at right angles, the feet unanchored, and the hands clasped behind the head. Subjects are instructed to curl-up until the elbows touch the thigh and return the hands to the mat (interlocked behind the head). Subjects perform curl-ups at a cadence of 25 curl-ups per minute until exhausted or until the cadence cannot be maintained. A maximum of 100 repetitions was allowed since few subjects reached this number, and any further curl-ups performed did not provide the experimenters with additional information. The mean curl-ups performed by the sample (N=117) was 49.7 (sd=23.7).

The relationship between a full sit-up 1-minute test and a partial curl-up 1-minute test was investigated by Robertson and Magnusdottir (1987). The full sit-up protocol required that the subject held the arms crossed across the chest and touched the thighs, while the feet were stabilized by an experimenter. In the partial curl-up protocol, subjects flexed the spine and slid the fingers to touch a frame placed at a distance of 7.62 centimeters from the starting position. Both tests required an all out

effort for 60 seconds. The correlation coefficient between the two protocols was .65 (N=19). The range of motion of the spine in the partial curl-up test was also investigated. The angle of the upper trunk from the exercise surface was 26.5° for males and 37.9° for females, at the apex of the curl-up, or when the finger tips had reached the 7.62 centimeter distance. The authors concluded that the partial curl-up protocol may discriminate against those individuals with poor spine flexibility, but that the test protocol is a better indicator of abdominal muscular function than the full sit-up protocol.

Faulkner and colleagues (1989) investigated the relationship between two partial curl-up protocols, and the reliability and objectivity of the tests. The first protocol was the same proposed by Jette and colleagues (1984) and adapted by the Canada Fitness Award. The second protocol was similar as the one described in Robertson and Magnusdottir (1987), except the distance reached by the finger tips was 12 centimeters (for subjects over 45 years of age, the distance was reduced to 8 centimeters). Both tests were performed to a cadence of 20 curl-ups per minute until the subjects exhausted. Significant differences were found in the number of partial curl-ups performed in the two protocols, more curl-ups could be performed in the second protocol (reach 12cm). A test-retest coefficient for the reliability of the

protocols was not reported, however the authors concluded that the first protocol appeared to be more consistent than the second.

The authors discussed the applicability of the two protocols and concluded that the second protocol was easier to standardize, and that the subjects had trouble maintaining the 140° knee angle required for the first protocol. The second protocol was recommended for adaptation in fitness batteries, especially those requiring mass testing, or the testing of sedentary individuals (Faulkner et al., 1989). The problem with changing the distances that a subject can reach forward with their fingertips, is that it becomes difficult to determine whether all subjects are taxing their abdominal musculature to the same extent. Thus, less flexible subjects for whom the distance is reduced, may not be contracting their abdominals to the same extent as more flexible subjects. This may place less flexible subjects at an advantage when performing the test, if their abdominal musculature is in comparable physical condition as a more flexible subject. For individuals who test yearly, comparisons before and after the age cut-off would be meaningless.

The YMCA (Golding et al 1989) uses a bent knee full sit-up protocol. The participant lays supine with knees at right angles, the feet stabilized by the experimenter, and the "fingers next to the ears", and touches opposite elbow to opposite knee in every repetition. The shoulders are returned to the mat. The test

requires as many sit-ups as possible in one minute. The test-retest reliability (.94) and inter-tester reliability (.98) are high (Johnson & Nelson, 1986). This test is also favored by the American College of Sports Medicine (ACSM) and is used in a great number of test batteries (Barrow & McGee, 1974; Johnson & Nelson, 1986; McCloy & Young, 1954). A 20 second variation of this test, in which the subject touches the chin to the knees without stopping was reported by Van Huss and Heusner (1970). A 30-second test, in which the elbows touch the knees was reported by Larson (1974). AAHPERD uses a modified version in which the subjects crosses the hands over the chest and the subject curls up until the elbows touch the thighs. The feet are stabilized, and the duration of the test is one minute (AAHPERD, 1980).

Reebok International (1991) proposed a protocol in which partial curl-ups are used. The participant lays supine with the knees at right angles, the hands pronated, the arms by the sides, and the feet stabilized by a partner. The participant curls-up and slides the fingertips a distance of three inches, then returns the shoulders to the exercise surface. Test-retest reliability, the size and composition of the standardization sample for the collection of the reported norms, and rationale for the given distance are not reported. Stabilizing the feet is not acceptable, as discussed previously, since the hip flexors are recruited and individuals may actually compensate for weak abdominals and do well in the test.

The test-retest reliability of a 1-minute half sit-ups test was investigated by Diener and Golding (1991). The subject lay supine with arms by the sides and hands pronated. The knees were bent at right angles, and the subject performed a half sit-up. The hands remained on the exercise surface and slid forward as the subject curled, to a distance 3.5" from the starting point. The subject performed as many half sit-ups as they could in one minute. The test-retest reliability was high (r=.967). The distance was determined by pilot trials, in which subjects of varied heights and arm lengths performed a partial curl-up until the angles of the scapulae were lifted off the exercise surface. Several subjects reported discomfort caused by the positioning of the hands, since most individuals perform the partial curl-up exercise with the hands clasped behind the head. In addition, motivation to perform, as it is usual in an exercising population, made some subjects depress their shoulders at the apex of the curl-up. This practice can result in an added advantage to those with good shoulder flexibility, giving them up to 1.5 inches of "extra" reach. It was concluded that the test was acceptable for testing, provided that experimenters can make the subject adhere to the procedure. A protocol which did not allow subjects the opportunity to gain an advantage would be more desirable.

In summary, most standardized tests of abdominal strength and endurance use full sit-ups or full curl-ups, both of which recruit the hip flexors. While a few partial

curl-up protocols exist, all have some problem regarding uniformity of testing across subjects, or across experimenters.

Summary of the Literature

Strength testing dates back to the mid 1800's, as interest was placed in the anthropometric and physical characteristics of athletes (Clarke, 1959; Massey, 1970). Measurement of muscular strength brought about the identification of explosive, isotonic, isometric, and later isokinetic strength (Cureton, 1947; DeLorme, 1951; Fleishman, 1964; Moffroid et al., 1969; McCloy, 1940). Instruments to measure strength developed as demands for portable, accurate, and short tests of strengths were required for field testing (Clarke, 1966; DeLorme, 1951; Johnson & Nelson, 1986; Mathews, 1973). As the strength of athletes was measured, it was found that muscular endurance was closely associated with muscular strength (Anderson & Kearney, 1981; Clarke, 1966; Hunsicker, 1974; Knapik, 1989). Tests to measure muscular strength and endurance require that a movement be repeatedly performed against resistance. In field testing, as in calisthenics, the body of the participant is often used as resistance as is the case in push-ups, chin-ups, and sit-ups (ACSM, 1991; Golding et al., 1989; Johnson & Nelson, 1986).

Much emphasis has been placed on exercising and testing the strength and endurance of the abdominal musculature. Reasons for this emphasis include the

aesthetic appeal of possessing a flat, toned abdomen (Golding et al., 1989), the importance of the abdominal musculature in maintaining good posture (Flint & Diehl, 1960; Peterson & Wheeler, 1988; Troup & Chapman, 1969), and the negative relationship between strong abdominals and the incidence of low-back pain (Donchin et al., 1990; Helewa et al., 1990; Langrana & Lee, 1984; Rasch & Allman, 1972).

In exercising the abdominal musculature, it was found that gains in strength due to exercise were coupled with gains in muscular endurance (Anderson & Kearney, 1982; Knapik, 1989; Mathews, 1973; Smidt et al., 1989). Although many exercises exist to attain and maintain abdominal strength and endurance (Clarke, 1976; Flint, 1965; Walters & Partridge, 1956), the sit-up has become one of the most popular. Sit-ups are performed by flexing the spine and the hips from a supine position (Bender & Shea, 1964; Ricci et al., 1981; Sodeberg, 1966). Variations include bending the knees at different angles, supporting the feet, placing the hands in different positions, and flexing the spine from 30° to 90° (Clarke, 1976; Gutin & Lipetz, 1969; Flint, 1965; Golding et al., 1989; Godfrey et al., 1977). The target muscles of the sit-up exercise are the rectus abdominis, and the internal and external obliques (DeLacerda, 1978; LeVeau, 1973; Sodeberg, 1966). The practice of the full sit-up requires that the hip flexor muscle group be recruited after the spine has been fully flexed by the abdominals. A half sit-up involves spine flexion only. Recruitment of the hip flexor

muscle group can be detected after the spine has been flexed 30° to 45° (Flint, 1965; LeVeau, 1973; Walters & Partridge, 1956).

Exercise scientists have used electromyographic studies (EMG) to determine the magnitude and duration of the involvement of specific muscles during the practice of a sit-up exercise. Most researchers agree that abdominal muscle (rectus abdominis, internal and external obliques) activity is maximized when the sit-up exercise is performed with the knees bent at 65° (Walters & Partridge, 1955), at 45° (Flint, 1965), or at 90° (LaBan et al., 1965). Hip flexor (iliopsoas, rectus femoris) activity was found to increase after the spine was flexed 30° when the legs were extended (LaBan et al., 1965), or to remain constant throughout the exercise (Godfrey et al., 1977). Supporting the feet while practicing the sit-up exercise was shown to increase hip flexor activity (Godfrey et al., 1977; LaBan et al., 1965), and to decrease rectus abdominis activity (Halpern & Bleck, 1979; Walters & Partridge, 1956). However, Flint (1965) found more activity in the lower rectus abdominis when the feet were supported, than when the feet were not supported. Results from later studies suggest that the half sit-up with the feet unsupported and the knees flexed, should be used for maximizing abdominal muscle activity and minimizing hip flexor activity (Godfrey et al., 1977; Halpern & Bleck, 1979).

Concerns have been raised regarding the performance of full sit-ups by a population of exercise enthusiasts. Full sit-ups have been shown to strengthen and tighten the hip flexor muscles (mostly the iliopsoas), therefore increasing the lumbar curve (Allsop, 1971; Flint, 1964; Rasch & Allman, 1972). The initiation of the full sit-up in the presence of weak abdominals also causes an increase in lordosis (Flint, 1964; LeVeau, 1973; Logan, 1965; Sodeberg, 1966). An increase in lumbar curve may contribute to increases in the incidence of low-back pain (Gilliam, 1976; Kendall, 1965; Peterson & Wheeler, 1988). The partial curl-up, or half sit-up has been recommended as a safer exercise, in terms of the lumbar spine (Allsop, 1971; Flint, 1965; Kendall, 1965), and as a better strengthening exercise for the abdominal musculature (Allsop, 1971; Gilliam, 1976; Sodeberg, 1966).

Current tests of abdominal strength and endurance include variations of a 1-minute full sit-up protocol (AAHPERD, 1980; ACSM, 1991; Golding et al., 1989), unlimited time full sit-up protocols (Johnson & Nelson, 1986; Mathews, 1973; Quinney et al., 1984), or a "pass-fail" full curl-up test requiring the performance of only one full curl-up (Faulkner et al., 1982). Partial curl-up protocols requiring unlimited repetitions were suggested by Faulkner and colleagues (1989), Jette and colleagues (1984), and a timed 1-minute protocol by Robertson and Magnusdottir (1987), Diener and Golding (1991), and by Reebok (1991). The current tests use

different criteria for determining a "legal" half sit-up, and it becomes difficult to determine whether all subjects are exerting the same effort. Most partial curl-up protocols require that the hands slide forward a certain distance, however this practice may put individuals with poor spine flexibility at a disadvantage, while favoring those individuals with good shoulder flexibility (Diener & Golding, 1991; Faulkner et al., 1989; Robertson & Magnusdottir, 1987). The need remains for a reliable and valid test of abdominal strength and endurance that uses a partial curl-up protocol.

Chapter 3

Methodology

The purpose of the current study was to investigate the reliability and validity of a 1-minute half sit-ups test. Three experiments were designed. In the first experiment, test-retest reliability was investigated by administering the same half sit-up test on two different occasions to the same subjects, and correlating the scores. A second experiment tested both concurrent validity and face validity. Concurrent validity was explored by correlating the scores obtained on a standardized test of abdominal strength and endurance (bent-knee full sit-ups), with a 1-minute half sit-ups test, the protocol being investigated in this study. Face validity was explored by correlating the scores of an isometric test of abdominal strength with the 1-minute half sit-ups test. To assure that all subjects were performing the half sit-up in exactly the same manner, three testing instruments were constructed, and inter-apparatus reliability was investigated in a third experiment.

Subjects

Subjects were 108 apparently healthy volunteers; there were 45 males (mean age=30.07, sd=14.66) and 63 females (mean age=28.63, sd=11.75). Subjects were recruited from the University and the community by advertisements in a faculty and staff weekly newsletter, and in the city newspaper. Percent body fat, aerobic fitness (measured by a 3-minute step test), and spine flexibility were collected in all experiments for two purposes: to obtain descriptive statistics of the sample, and to allow for possible explanation of results. Table 1 presents descriptive statistics for the sample.

Statistical Design

Pearson Product Moment correlation coefficients were used as reliability and validity coefficients. This statistic is the recommended coefficient for test-retest reliability, inter-apparatus reliability, concurrent validity, and face validity (Anastasi, 1989). Correlated t-tests were used to identify any significant differences between trials. A within subjects one-way analysis of variance (ANOVA) was used to investigate significant differences between trials for the three testing instruments. An intra-class reliability coefficient was computed using the ANOVA table. In addition, step-wise multiple regressions were computed to identify predictive variables for both the full sit-up and the half sit-up tests.

Table 1

Subject Descriptive Statistics

Entire sample N=108	Statistics			
Variables	Mean	SD	Min	Max
Age	29.22	13.01	11	72
Height (inches)	66.91	4.31	57	78
Weight (pounds)	148.57	28.62	105	230
% Body Fat	19.78	6.93	4.4	32.8
Recovery HR*	105.12	21.03	58	151
CR Fitness Level**	3.61	2.01	1	7
Flexibility	17.22	4.52	6	27

Females N = 63	Mean	SD	Min	Max
Age	28.63	11.75	11	67
Height (inches)	64.98	3.47	58	78
Weight (pounds)	133.32	17.22	105	186
% Body Fat	22.84	4.91	12.6	32.8
Recovery HR*	108.71	22.04	67	145
CR Fitness Level**	3.65	2.17	1	7
Flexibility	18.55	4.05	9	27

Males N = 45	Mean	SD	Min	Max
Age	30.07	14.66	18	72
Height (inches)	69.61	3.91	57	76
Weight (pounds)	169.93	27.82	120	230
% Body Fat	15.49	7.12	4.4	29.9
Recovery HR*	100.08	18.61	58	151
CR Fitness Level**	3.55	1.79	1	7
Flexibility	15.36	4.51	6	25

* Kasch 3 minute step-test

** Cardiorespiratory Fitness Levels 1=Excellent 2=Good
3=Above average 4=Average 5=Below average 6=Poor 7=Very poor

Variables

The descriptive variables, aerobic fitness, percent body fat, and spine flexibility were collected for each of the three experiments. The procedures followed to obtain these measures were common to the three experiments and are outlined in this section. Procedures specific to each of the experiments are discussed in the methodology section of the experiments.

Flexibility - Spine flexibility may influence an individual's performance in the sit-up and half sit-up test, since spine flexion is required to perform these tests. Thus, spine flexibility data was collected in order to explain the possible poor performance or failure of a subject with poor spine flexibility to perform the sit-up tests. A standard sit-and-reach flexibility board was utilized to determine the subjects spine and hip flexibility (Golding et al., 1989). The subject sat, without shoes, on the sit-and-reach flexibility board, with the heels against the 15 inch mark of the measuring tape. The subject then reached with both hands toward the feet along the tape, flexing the trunk and hips forward. The distance reached by the subjects fingertips was recorded to the nearest half inch.

Aerobic Fitness level - Aerobic fitness level was measured to allow for possible explanation of very poor performances and very good performances. Subjects who could not perform the sit-up test, or who stopped the test early would presumably also

show poor scores on the aerobic fitness test. Aerobic fitness level was determined by a 3-minute step-test. A 12" bench, a lab timer, and a metronome were utilized to perform the test. Subjects stepped up and down on a 12" bench at a rate of 24 steps per minute. The pace was maintained by a metronome. Subjects stepped continuously for 3 minutes, after which they immediately sat on the bench, and recovery heart rate was taken for a full minute, started within 5 seconds of termination of the stepping phase. The recovery heart rate was used to obtain an aerobic fitness classification, according to national norms (Golding et al., 1989).

Percent Body Fat - A very obese individual, or one who has an excess accumulation of fat around the waist may be hampered in the performance of the sit-ups tests. In order to explain a possible poor performance of the tests caused by excess fatness, percent body fat was measured. Percent body fat was determined for each subject by four skinfold measurements using Lange calipers. The Jackson-Pollock sum of four sites (abdomen, ilium, triceps, and thigh) and age prediction equation tables were used to determine body fat percent (Golding et al., 1989).

Materials (Forms)

Informed Consent - Informed consent was obtained for each of the three experiments at the beginning of the first testing session (Appendix B).

Questionnaires - The Par-Q form was completed by each subject. In addition, a questionnaire regarding the subject's exercise habits, low-back health history and present status, and any experience with half sit-ups, was completed (Appendix C).

Subject Results and Information Form - After the completion of the experiment, subjects were given the results of the 3-minute step test, the flexibility test, an assessment of body composition, and the number of sit-ups performed. Subjects were also given the YMCA's norm tables (Golding et al., 1989) appropriate for their age and gender, so comparisons to the normative values could be made. Subjects also received general information on how to improve their physical fitness in the four areas tested (body composition, flexibility, recovery heart rate, and abdominal strength and endurance). The recommendations included the American College of Sports Medicine exercise frequency, intensity, and duration guidelines, as well as recommendations for improving in the specific areas tested (ACSM, 1990) (Appendix D).

Procedure

The duration of the testing sessions was approximately 35-50 minutes, and took place in the Exercise Physiology laboratory. Upon arrival, subjects read and signed the consent form, and completed the Par-Q and the questionnaire. Subjects with a history of low-back trouble were advised to immediately terminate the session if any back discomfort occurred. Subjects were then assigned to 1 of 3 experiments: a test-

retest reliability study, a validity study, or an inter-apparatus reliability study. An effort was made to equate the number of males and females within each study, and to assure that the age distribution in the studies was similar.

Experiment 1 - Test-Retest Reliability

This experiment investigated the test-retest reliability of a 1-minute half sit-ups protocol. Subjects performed the half sit-ups test on two different trials and the scores obtained were correlated.

Subjects

Twenty-two females (mean age=24.91, sd=9.11) and 15 males (mean age=28.53, sd=15.99) participated in this experiment. Descriptive statistics for this sample are presented in Table 2.

Materials, Apparatus, and Procedures

A neoprene exercise mat was used as a pad on which to perform the half sit-ups. A laboratory timer, set to 1 minute, was used to time the duration of the half sit-up test. The half sit-up apparatus (Apparatus A) was designed specifically for this study, and constructed by the investigator (Appendix E). The design was intended to assure that all subjects performed the half sit-ups in exactly the same manner, that is, they curled up until the inferior angles of the scapulae lifted from the exercise surface.

Table 2

Descriptive Statistics - Test-retest Reliability

Entire sample N=37	Statistics			
Variables	Mean	SD	Min	Max
Age	26.37	12.29	11	72
Height (inches)	67.22	4.11	59	76
Weight (pounds)	147.41	24.42	108	205
% Body Fat	19.29	6.92	4.4	30.2
Recovery HR*	104.05	19.71	71	145
CR Fitness Level**	3.64	1.97	1	7
Flexibility	17.79	4.38	8	26

Females N = 22	Mean	SD	Min	Max
Age	24.91	9.11	11	43
Height (inches)	65.41	3.27	59	72
Weight (pounds)	135.95	16.34	108	180
% Body Fat	23.01	4.68	12.6	30.2
Recovery HR*	109.27	20.94	71	145
CR Fitness Level**	3.82	2.17	1	7
Flexibility	19.16	4.11	9	26

Males N = 15	Mean	SD	Min	Max
Age	28.53	15.99	18	72
Height (inches)	69.86	3.83	63	76
Weight (pounds)	164.21	24.99	130	205
% Body Fat	13.86	6.06	4.4	24
Recovery HR*	96.41	15.33	73	130
CR Fitness Level**	3.4	1.68	1	7
Flexibility	15.8	4.11	8	21

* Kasch 3 minute step-test

** Cardiorespiratory Fitness Levels: 1=Excellent, 2=Good, 3=Above average, 4=Average, 5=Below average, 6=Poor, 7=Very poor

Materials and instructions needed for assembly of the half sit-up apparatus are listed in Appendix E.

Procedure

1. Subject was instructed to lay supine on the exercise mat, with knees at right angles (90°) and the feet flat on the mat (see Figure 5). The positioning of the arms was chosen by the subject. Subjects were instructed to either grasp the hands behind the neck, or cross them on the chest.

2. Subject was instructed to perform one half sit-up, by flexing the head and the upper trunk in a curl until the inferior angles of the scapulae were lifted from the exercise mat.

3. A wedge was placed under the subject so that the angles of the scapulae rest directly on edge of the surface closest to the ground (See Figure 5).

4. The apparatus was adjusted to the correct height by sliding the movable arm along the upright until the contact plate was at the height of the subject's frontal bone. The holding pins were inserted in the proper hole, at the height desired, and the wing nuts were secured onto the pins. This was necessary to keep the arm from swaying side to side as the subject touched the contact plate.

5. Subject was instructed to flex the head completely and the apparatus was adjusted to the correct horizontal distance from the subject by sliding the entire apparatus

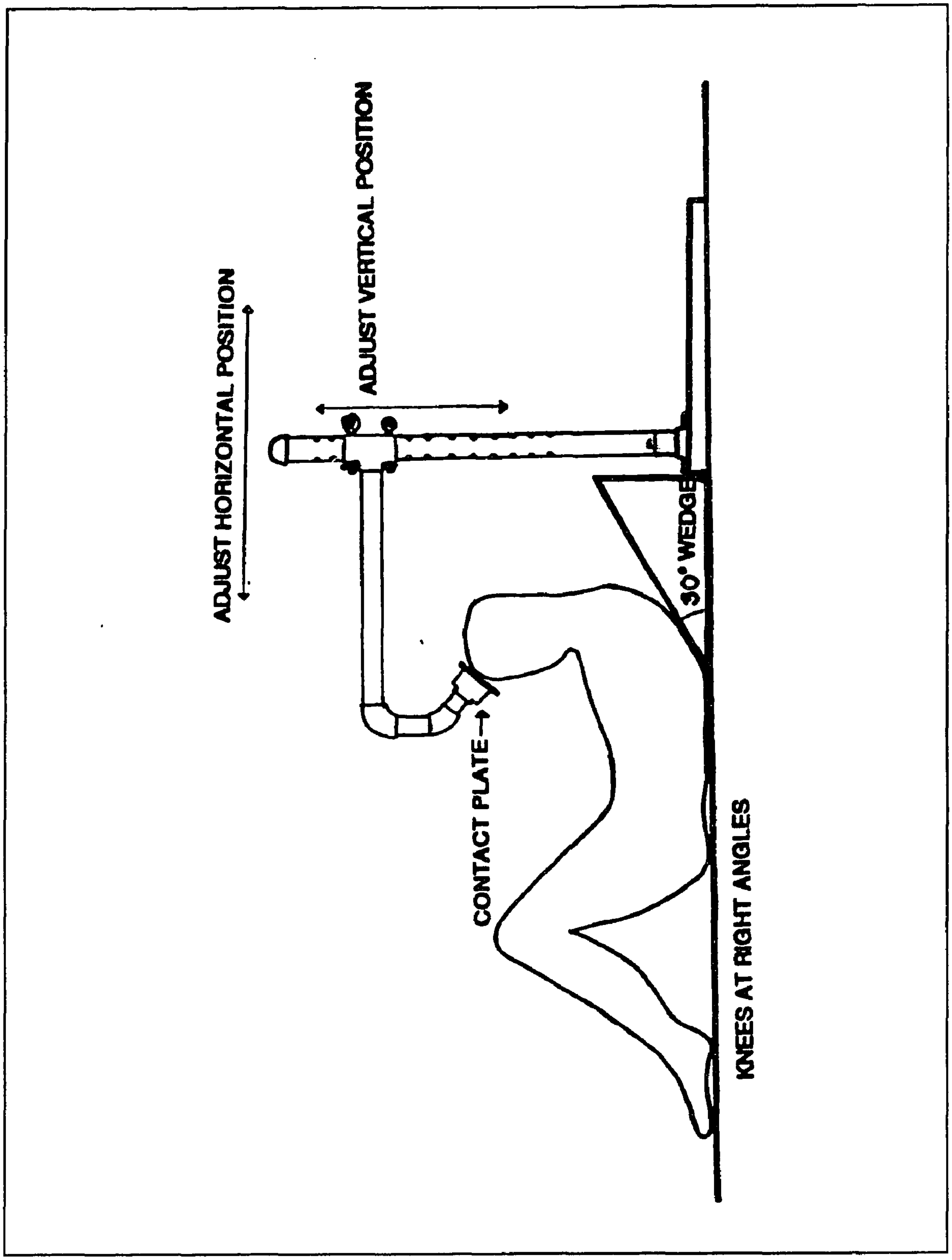


Figure 5 - Positioning of subject with Apparatus A

along the ground until the contact plate was directly in contact with the frontal bone of the subject. The head was flexed to its maximum reach, and a mechanical lap counter behind the plate was depressed. The purpose of this adjustment was to allow the subject to trigger the contact plate (and thus the counter) at the maximum reach of their curl. The wedge was then removed from under the subject and the subject remained supine on the exercise surface.

6. Subject was instructed to perform a minimum of 2 and a maximum of 4 trial half sit-ups, assuring that the subject's forehead triggered the counter on the up position, and that the scapulae returned to the mat on the down position. Subjects were corrected if the sit-ups were not performed correctly. At this point any final adjustments to the positioning of the apparatus were made. The total time involved in adjusting the apparatus including final adjustments was approximately one minute.

7. The counter was re-set to zero. Subjects were instructed to perform as many half sit-ups as they could in one minute. When subjects initiated the first half sit-up, a 1 minute timer was started.

8. The experimenter encouraged the subject and monitored the scapulae to make sure that they returned to the exercise mat on each repetition (the neck could remain flexed). Any "illegal trials" were subtracted from the total count, and the subject was corrected verbally. Thirty and 50 second warnings were given and the test was stopped

at the completion of one minute. The total number of "legal" sit-ups registered on the counter were recorded.

9. Skinfold measurements, the 3-minute step-test, and the flexibility test were given. The subject was then given a brief rest, the fitness tests were scored and shared with the subject. The time interval between the fitness tests and the second set of half sit-ups was approximately 3 to 6 minutes. The time interval between the two half sit-up tests varied from 12 to 18 minutes.

10. The subject performed the second set of half sit-ups exactly as before. The number of half sit-ups performed was recorded.

Experiment 2 - Validity

The concurrent validity and face validity of a 1-minute half sit-up protocol was investigated in the second experiment. Concurrent validity was tested by correlating the scores of a current standardized 1-minute sit-up test with the proposed protocol (1-minute half sit-ups). Face validity was tested by correlating the scores of the proposed 1-minute half sit-ups protocol with an isometric test of strength.

Subjects

Twenty-one females (mean age=26.02, sd=11.56) and 15 males (mean age=28.26, sd=13.47) participated in this experiment. Descriptive statistics for this sample are presented in Table 3.

Materials, Apparatus, and Procedures

The half sit-up apparatus (Apparatus A) discussed in experiment 1 was also utilized in this experiment. A neoprene exercise mat was used as padding to perform the YMCA protocol full sit-ups test, and the half sit-ups test. A laboratory timer was used to time both sets of sit-ups.

<u>Strength Table</u> (Appendix F)

-The strength table was used to measure isometric strength of the hip flexors and the spine flexors. The strength table was originally constructed for a study designed to determine the reliability of 15 different muscle groups. The design of the table, the number of trials, and the testing positions were based on Harrison Clarke's work (Clarke, 1965), and attempted to isolate and maximize the pull of a particular muscle group in a standardized fashion (Depew, 1986). The tension exerted by the pull was measured by a load cell and was read on a digital display to the nearest .5 kilogram.

The strength table and accesories featured:

-A padded surface to place the subject in the various testing positions.

Table 3

Descriptive Statistics - Validity

Entire sample N=36	Statistics			
Variables	Mean	SD	Min	Max
Age	26.95	12.25	17	68
Height (inches)	67.11	4.49	58	78
Weight (pounds)	151.27	31.41	108	230
% Body Fat	19.12	6.68	4.6	32.8
Recovery HR*	107.25	21.31	71	151
CR Fitness Level**	3.83	2.07	1	7
Flexibility	17.34	4.67	8.5	27

Females N = 21	Mean	SD	Min	Max
Age	26.02	11.56	17	67
Height (inches)	65.14	4.41	58	78
Weight (pounds)	134.09	21.03	108	186
% Body Fat	21.8	4.91	13.9	32.8
Recovery HR*	107.43	22.92	71	142
CR Fitness Level**	3.66	2.33	1	7
Flexibility	18.14	4.38	9	27

Males N = 15	Mean	SD	Min	Max
Age	28.26	13.47	18	68
Height (inches)	69.86	2.97	64	74
Weight (pounds)	175.33	27.77	130	230
% Body Fat	15.38	7.18	4.6	28.3
Recovery HR*	107	19.58	73	151
CR Fitness Level**	4.06	1.71	1	7
Flexibility	16.23	4.98	8.5	25

* Kasch 3 minute step-test

**Cardiorespiratory Fitness Levels: 1=Excellent, 2=Good,
3=Above average, 4=Average, 5=Below average, 6=Poor, 7=Very poor

-A center rail (bottom) and two outside upright rails with adjustable eyelets to anchor the cable of the load cell.

-A center opening in the padded surface to thread the cable of the load cell, and permit the load cell to be attached to the subject and anchored to the bottom rails.

-Two metal rod side rails to secure the straps which stabilized the subject to the table during testing.

-Two 3-inch belts with hook-and-stick (Velcro) tape to isolate the muscle group desired. The center of the belts were placed snugly over the subject and the ends of the straps were secured around the side rails.

-Two padded straps of different lengths to attach the load cell to the body part to be tested. A "D" ring sewn to the strap, was used to attach the load cell, and the straps were secured with Velcro tape around the subject.

-The load cell with a cable, a turnbuckle, and "S" hooks attached to the "D" ring worn by the subject on one end, and to the adjustable eyelets of the bottom center rail of the table on the other end (Figure 6).

-The digital display was placed at a point where it could be read during testing.

-A ruler to measure the positioning of the strap on the thigh during testing of hip flexor strength (6 inches from the inguinal line).

Procedure

1. Subjects read and signed the consent form, and completed the Par-Q and the demographic questionnaire.

2. Half of the subjects performed the half sit-up test described above, the other half the YMCA's full sit-up test, assigned at random. The purpose of randomizing the order of the sit-up tests was to equate any muscular fatigue. The half sit-up test protocol is described in Experiment 1.

-The full sit-up test protocol has the subject supine with the knees at right angles, the feet flat, and the hands clasped behind the neck.

-The subject's feet were held securely, and the subject flexed the spine and hips, touching opposite elbow to opposite knee alternatively on each sit-up.

-The shoulders returned to the mat on each sit-up, and the subject performed as many sit-ups as they could in one minute. The number of sit-ups performed were recorded.

3. Skinfold measurements were taken to determine percent body fat.

4. The subject performed the 3 minute step-test, and the flexibility test.

5. Abdominal isometric strength was measured by testing the strength of the spine flexor muscle group (Figure 6).

-The subject lay supine on the strength table, with the upper trunk directly on the round opening of the padded surface. The knees were flexed at right angles and the

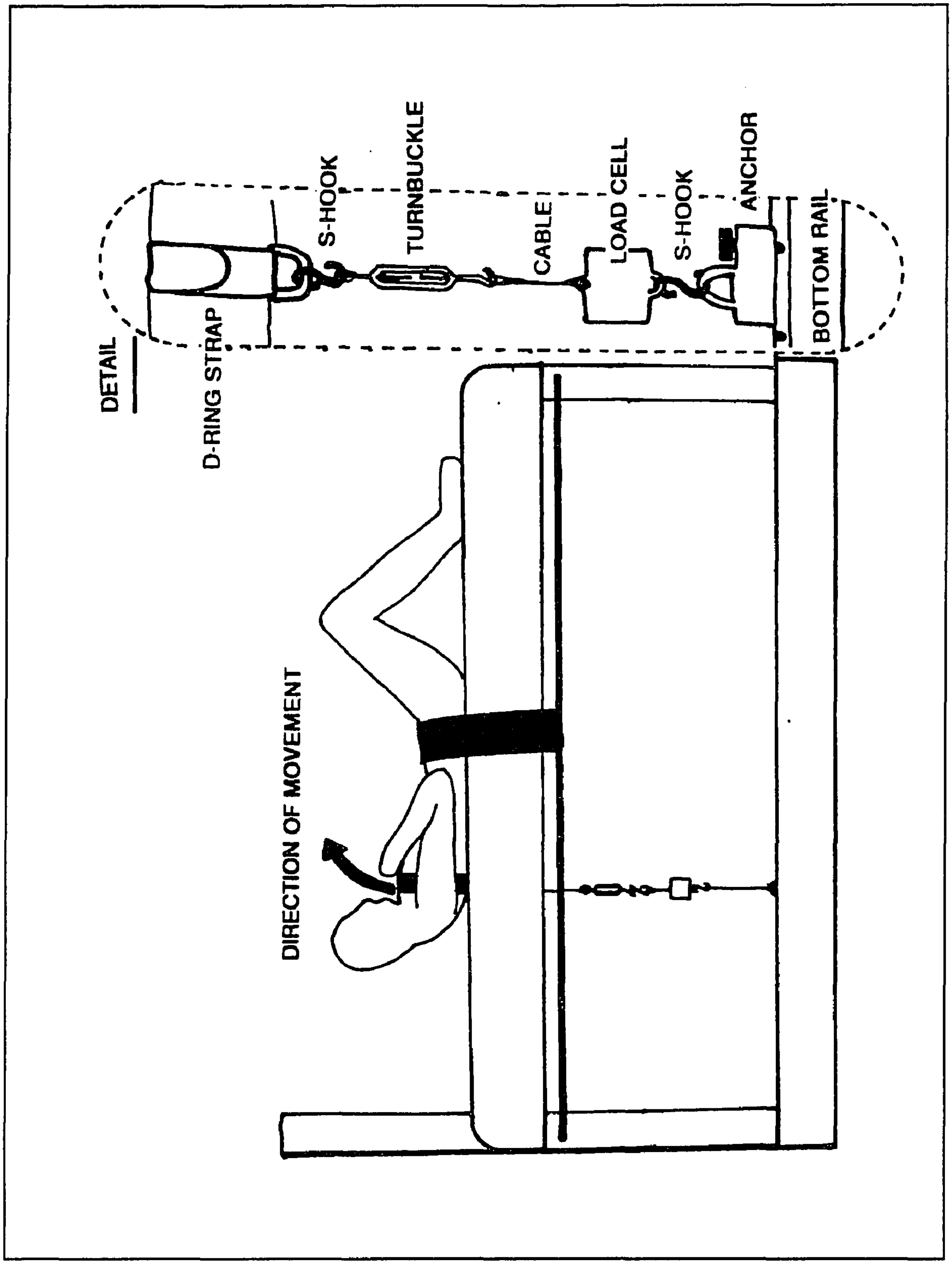


Figure 6 - Isometric strength measuring / Spine flexion

feet remained on the padded surface. The 90° angle of the knee joint was measured with a goniometer. The forearms were crossed on the chest.

-A "D" ring strap was secured snugly around the subject's upper trunk, directly below the axilla. The ring was placed between the scapulae, and it was visible from under the table through the round opening.

-The subject was firmly secured to the table with the 3-inch belts across the crests of the ilia.

-The load cell was attached to the "D" ring with an "S" hook, and to an eyelet of the bottom center rail, adjusted directly under the round opening. The turnbuckle was tightened until the load cell registered .5 kilograms, and then loosened until the display read 0 kilograms. This procedure limited the subject from lifting the trunk from the surface of the table anymore than two inches.

-The subject was instructed to flex the spine "as hard as possible, while keeping the feet on the table, and hold the flexed position for two seconds." The highest number registered on the display was recorded to .5 kilogram accuracy. Two trials were given, the highest result was used and represented abdominal (spine flexor) strength. The interval between the trials varied from 30 seconds to 1 minute.

6. Hip flexor strength was assessed by measuring the isometric strength of the hip flexor muscle group (Figure 7).

-The subject lay supine with the hands crossed over the chest. The subject was positioned so that the leg to be tested was placed directly over the narrow opening of the strength table. The legs were tested independently. The leg not tested rested extended on a leg brace.

-One of the 3-inch belts was placed across the crests of the ilia as before, the other was placed across the chest at mid-sternum. The belts were secured firmly to the side rails.

-A "D" ring strap was secured around the leg to be tested, with the ring placed in the opening. The strap was placed exactly 6 inches from the inguinal line. This assured that the length of the lever's resistance arm was the same for all subjects.

-The load cell was attached to the "D" ring with an "S" hook, and to the adjusted eyelet on the bottom center rail. The turnbuckle was tightened so that .5 kilograms read on the display, and then loosened until the display read 0 kilograms.

-The subject was instructed to "flex the hip without bending the knee, as hard as possible, and hold the pull for two seconds". The highest weight registered was recorded to the nearest .5 kilogram. Two trials were given for each leg. Hip flexor strength was determined by the sum of the highest trial for each leg.

7. The subjects were given a brief rest, in which the experimenter discussed the results of the fitness tests, and gave any recommendations, or answered any questions. This rest varied from 3 to 6 minutes depending on the fitness level of the subject.

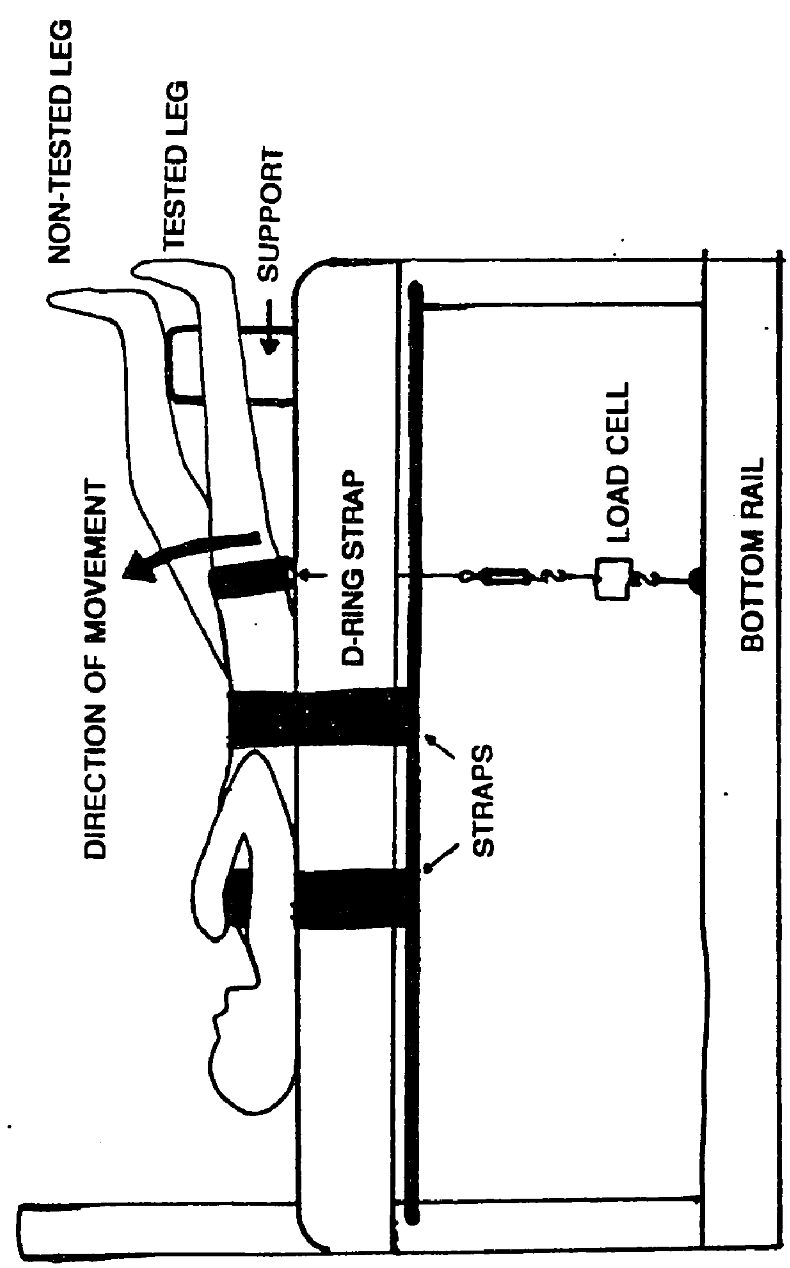


Figure 7 - Isometric strength measuring / Hip flexion

8. The subject performed either the half sit-up test or the full sit-up test that was not previously performed. The number of correct sit-ups was recorded.

Experiment 3 - Inter-apparatus Reliability

Subjects

Twenty females (mean age=35.45, sd=12.09) and 15 males (mean age=33.4, sd=14.86) participated in this study. Descriptive statistics for this sample are presented in Table 4.

Materials, Apparatus, and Procedures

Three testing instruments were tested for inter-apparatus reliability. Measuring the extent to which a subject curls during a half sit-up, can be achieved in several ways. Apparatus A (Figure 5) measured the height of the lift directly, by forcing the subject to touch a contact plate with the forehead. The contact plate was adjusted so that when the subject touched the plate with the forehead, the inferior angles of the scapulae were lifted from the exercise surface. Apparatus B (Figure 8) measured the distance that a subject must slide the hands forward, in order to assure that the inferior angles of the scapulae were lifted from the exercise surface. The experimenter assured that the hands reached the predetermined distance on each half sit-up, and that the shoulders return to the surface. This apparatus was tested in a previous study and

Table 4

Descriptive Statistics - Interapparatus reliability

Entire sample N=35	Statistics			
Variables	Mean	SD	Min	Max
Age	34.57	13.18	18	63
Height (inches)	66.38	4.38	57	76
Weight (pounds)	147.03	30.31	105	230
% Body Fat	20.96	7.23	4.6	32.3
Recovery HR*	104.06	22.51	58	142
CR Fitness Level**	3.34	2.01	1	7
Flexibility	16.51	4.53	6	24

Females N = 20	Mean	SD	Min	Max
Age	35.45	12.09	18	56
Height (inches)	64.35	2.51	60	69
Weight (pounds)	129.6	13.54	105	151
% Body Fat	23.77	5.14	14.6	32.3
Recovery HR*	109.45	23.34	67	142
CR Fitness Level**	3.45	2.09	1	7
Flexibility	18.34	3.77	11	24

Males N = 15	Mean	SD	Min	Max
Age	33.4	14.86	18	63
Height (inches)	69.1	4.92	57	76
Weight (pounds)	170.27	31.15	120	230
% Body Fat	14.38	6.61	6	30
Recovery HR*	96.87	19.84	58	131
CR Fitness Level**	3.2	1.97	1	7
Flexibility	14.07	4.41	6	22

* Kasch 3 minute step-test

**Cardiorespiratory Fitness Levels: 1=Excellent, 2=Good, 3=Above average, 4=Average, 5=Below average, 6=Poor, 7=Very poor

determined to have high test-retest reliability (r=.97) (Diener & Golding, 1991). Apparatus C (Figure 9) was a modification of Apparatus B. The inferior angles of the scapulae rested on a switched plate. The switch was triggered each time the subject depressed and released the switch. A mechanical counter registered each cycle as one sit-up. Apparatus A was described in Experiment 1.

Apparatus B (Appendix G)

A plywood board (dimensions 26" x 48" x 1/2") with a 1/4" neoprene pad attached, was utilized. Two strips of self-adherent black hook-and-stick tape (Velcro) (6" x 1") were placed, rough side up, perpendicular to the length of the plywood and against the side edges of the mat (Appendix G). Only the rough side of the velcro was used. The first strip was placed approximately 3' from the top edge of the plywood, and the second strip was placed 3.5" (8.89cm) apart. The 3.5" distance between the strips of velcro was determined from several pilot trials on subjects with different arm, trunk, and leg lengths. A human outline was painted on the exercise mat with white paint to aid the subjects in properly visualizing their position on the mat.

Apparatus C (Appendix H)

This apparatus was a modification of Apparatus B. A switched plate was placed under the inferior angles of the scapulae of the subject, thus the experimenter did not have to assure that the scapulae were lifted and returned to the ground. The

plate was wired to a mechanical counter that advanced once, each time the plate was depressed and released. Materials and instructions for constructing Apparatus C are listed in Appendix H.

Procedure

1. Subjects read and signed the consent form, and completed the Par-Q and the demographic questionnaire.

2. The order in which the testing instruments were used was counterbalanced to equate any possible muscle fatigue. Subjects were given an assigned "order" (such as apparatus A first, B second, and C third). All orders received the same number of subjects, that is, the same number of subjects were assigned to "order A-B-C" as to "order B-C-A", etc.

3. Subjects performed one of the three protocols for the 1-minute half sit-ups test. The procedure for administering the half sit-up test using Apparatus A was outlined in Experiment 1. The procedure for administering the 1 minute half sit-up test was the same for Apparatuses B and C, and is outlined below.

- Subjects lay supine on the sit-up test mat, with the knees bent at right angles, the arms by the sides, and the hands pronated (Figures 8 and 9). The finger tips of each hand were placed on the first strip of velcro. The experimenter, standing astride the subject, assured that the shoulders and trunk were completely straight, and that the

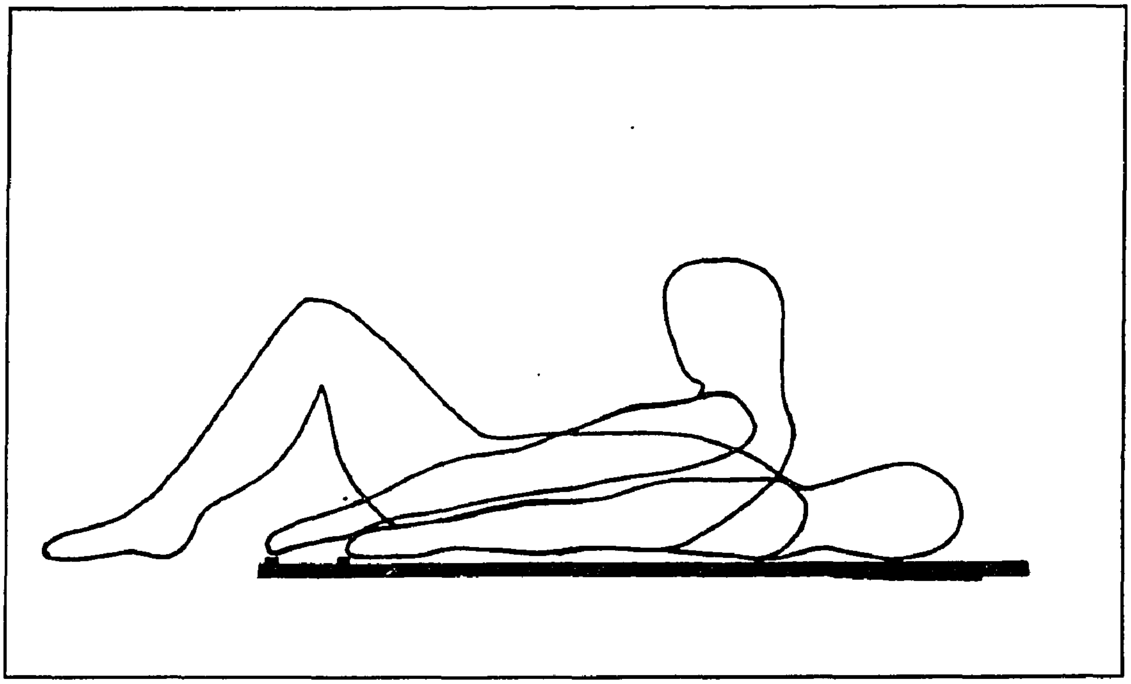


Figure 8 - Positioning of subject with apparatus B and correct half sit-up

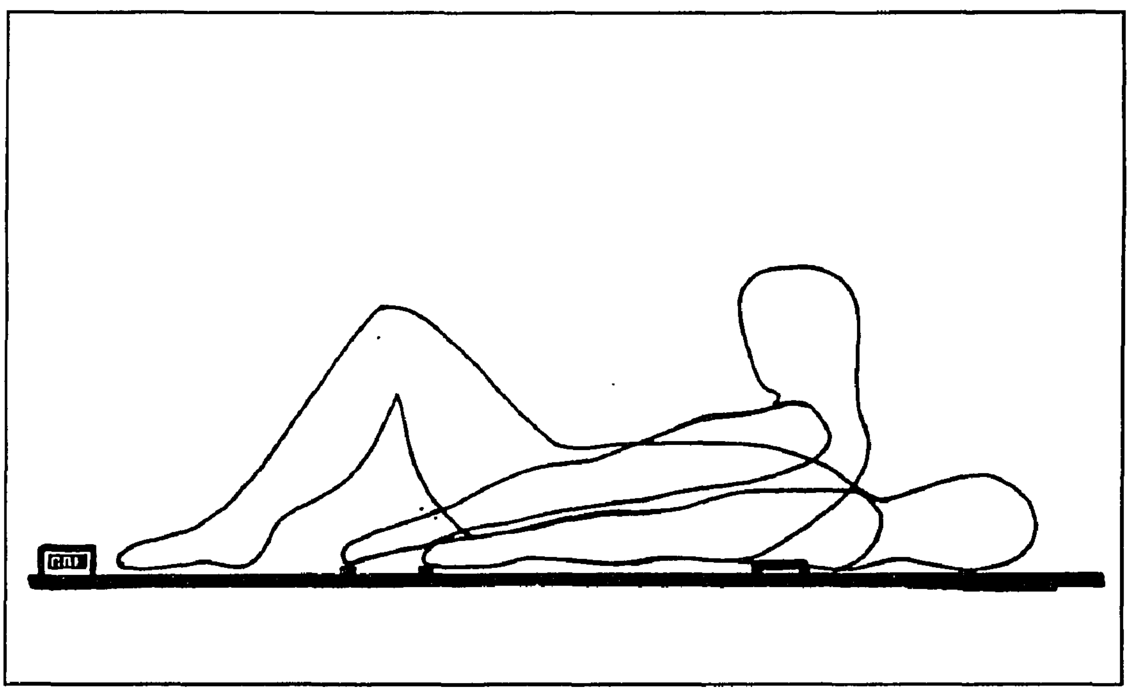


Figure 9 - Positioning of subject and apparatus C and correct half sit-up

shoulders were in a normal position (not depressed nor elevated). In Apparatus C, the switched plate was adjusted so that it was placed directly between the inferior angles of the scapulae of the subject.

-Subjects were asked to perform four trial abdominal curls. They were given instructions to flex the spine, lifting the head and the scapulae off the mat while keeping the arms extended, so that the hands slid on the mat and the finger tips reached the second strip of velcro. Upon return to the mat, subjects were told to extend the trunk so that their finger tips returned to the starting position, and the scapulae touched the mat. After four trials, subjects were allowed re-adjust their body position on the mat, so that the half sit-ups could be properly performed. The switched plate was re-adjusted as needed.

-Subjects then performed as many half sit-ups as they could in 1 minute. When the subject started the sit-ups, a timer was started. The experimenter counted, with a hand counter, the number of half sit-ups in which the subject reached the second piece of velcro with the fingertips and in which the shoulders were returned to the mat. Since Apparatus C automatically recorded the correct number of sit-ups, no hand counter was necessary when using this apparatus. The total number of correct sit-ups performed in 1 minute were recorded.

4. Skinfold measurements were taken and percent body fat was computed and recorded.

5. The three minute step test was administered.

6. The subject performed the second half sit-up test, according to the order assigned.

7. The flexibility sit-and-reach test was administered.

8. The subject was given a brief rest, during which the result of the fitness tests were discussed and any questions were answered. The duration of the rest period varied from 3 to 6 minutes depending on the fitness level of the subject.

9. The third half sit-up test was administered, according to the order assigned. Although there was some concern regarding the administration of three "all out" tests within the same 40-45 minute period, the data indicated that only the very unfit subjects (N=2) were affected by the procedure. These subjects performed significantly worse on the last set of sit-ups.

Chapter 4

Results and Discussion

Experiment 1 - Test-Retest Reliability

The test-retest reliability of Apparatus A (head touches contact plate) was studied in this experiment and will be discussed presently. The test-retest reliability of Apparatus B (hands reach 3.5") was studied in a previous experiment, and was found to be high (r=.967, p<.001) (Diener & Golding, 1991). The test-retest reliability of Apparatus C (switch under scapulae), was not included in this study, since this apparatus was considered to be identical to Apparatus B, with the exception that the switch leaves the experimenter free of the task of monitoring the subject's scapulae (i.e., the "down" phase of the sit-up). The remainder of the procedure was identical to that used with Apparatus B, and it was assumed that the test-retest reliability did not need to be calculated separately.

The mean half sit-ups performed with Apparatus A in trials one and two are shown in Table 5. A Pearson Product Moment correlation coefficient was computed

Table 5

Test-retest reliability - Means, difference, and statistics

	Statistics				
	Mean	SD	Difference	T-value	r
Half sit-ups test	55.16	17.96			
Retest	58.27	19.44	-3.11	-2.76*	0.936**

* p<.01 ** p<.001

between the number of sit-ups performed in each set. The results indicated that test-retest reliability was high (r=.936, p<.001), making this a reliable protocol for the half sit-ups test.

A paired-sample t-test was computed between the number of half sit-ups performed in the first and the second set. Results indicated a significant difference between the means (t=-2.76, p<.01). Subjects performed more half sit-ups in the second set (mean difference = 3.11). The results may have been due to a learning effect. The protocol and the apparatus were both new to the subjects, thus it was assumed that on the second set of half sit-ups, subjects knew the procedure and were able to perform better. Additionally, after the first set of sit-ups, subjects may have learned how to pace themselves better during a 1-minute "all out" effort. The

Table 6

Validity - Means and standard deviations for dependent variables

Entire sample N=37	Statistics			
Variable	Mean	SD	Minimum	Maximum
1/2 sit-ups *	53.75	15.55	19	82
Full sit-ups *	34.51	9.02	8	48
Left hip strength **	44.58	16.72	17	96
Right hip strength **	46.87	18.34	23	105
Total hip strength **	91.46	34.37	40	201
Average hip strength **	45.73	17.19	20	100.5
Abdominal strength **	17.26	8.01	4.5	41

* 1-minute test, maximum effort

** isometric strength expressed in kilograms

Table 7

Experiment 2 - Validity

Correlation matrix

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Age	1.00									
2. Height	-.09	1.00								
3. Weight	.03	.75***	1.00							
4. % Body fat	.19	-.01	.08	1.00						
5. CR fitness	-.13	.14	.24	.44**	1.00					
6. Flexibility	-.13	-.19	-.06	-.27	-.25	1.00				
7. Abdominal strength	.10	.09	.20	-.52***	-.31	.19	1.00			
8. Full sit-ups	-.11	.06	.03	-.58***	-.39*	.09	.13	1.00		
9. Hip strength	.22	-.07	.16	-.16	-.21	-.01	.63***	-.07	1.00	
10. 1/2 sit-ups	.03	.08	-.00	-.59***	-.57***	.10	.44**	.69***	.13	1.00

* $p<.05$ ** $p<.01$ *** $p<.001$

The absence of a higher correlation between the half sit-up test and the full sit-up test, is thought to be due to the different muscle groups used while performing full sit-ups. As previously discussed, the full sit-up protocol uses the hip flexor muscle group in addition to the abdominals. The correlation coefficient, however, was sufficiently high to conclude that there was a strong relationship between the current standardized full sit-ups test, and the proposed half sit-ups protocol.

Face validity

A Pearson product moment correlation coefficient was computed between isometric abdominal strength and the number of sit-ups performed in the half sit-ups test. The result (r=.439, p<.01) indicated a fair relationship between abdominal strength and the half sit-ups protocol. Subjects who demonstrated higher isometric abdominal strength also performed more half sit-ups in one minute.

This correlation coefficient was similar to ones obtained in previous research studies (Berger, 1965; Harvey & Scott, 1965; Wedemeyer, 1945). The half sit-ups test is meant to be a test of abdominal strength and endurance, by using repetitive concentric contractions of the abdominal muscle group. Since the endurance component is coupled with the strength component in the half sit-ups test, it was expected that all of the variance in the sit-ups test would not be accounted for by the isometric strength test. In addition, the half sit-ups test utilizes isotonic contractions,

whereas the measure of abdominal strength was an isometric test. The variance shared by isometric and isotonic strength was reported to be 48% (Knapik et al., 1983), leaving 52% of the variance due to factors other than strength, or error. It is possible that some of the error variance that is not shared by isotonic and isometric measures affected the relationship between the half sit-ups test (isotonic), and the measure of isometric strength.

A correlation coefficient was also computed between the full sit-ups test of abdominal strength and endurance and isometric abdominal strength. The correlation coefficient (r=.135, p>.05) was not significant, indicating that, in this sample, there was no relationship between abdominal isometric strength and the full sit-ups protocol. Thus, the half sit-ups test had a higher, and a significant correlation with abdominal strength, whereas the full sit-ups test did not. Excluding the endurance component, the half sit-ups test was a better representative of abdominal strength.

Of additional interest were the correlations between hip strength and the full sit-ups test, hip strength plus abdominal strength and the full sit-ups test, and fitness level and both sit-ups protocol. Since full sit-ups use the hip flexor muscle group in addition to the abdominal muscle group, the relationship between hip strength and full sit-ups was explored. A Pearson product moment correlation coefficient computed for the above variables (r.=-.069, p>.05), indicated that no relationship existed between

isometric hip strength and the number of full sit-ups performed. A compound variable was created by computing the algebraic sum of isometric hip strength and isometric abdominal strength, since both of these muscle groups are used while performing full sit-ups. A Pearson correlation coefficient computed between the hip-plus-abdominal strength variable and full sit-ups (r=.032, p>.05) yielded a non-significant correlation.

The lack of a relationship between the above variables was puzzling. Since the half sit-ups test correlated moderately with isometric abdominal strength, it had been assumed that the full sit-ups test would correlate in the same manner with isometric strength of the muscle groups which it utilizes. The explanation may lie in the difference between isometric and isotonic strength measurements. The present study measured isometric strength, while full sit-ups require concentric (isotonic) contraction of the muscle groups. The shorter range of motion of the half sit-up, may make the exercise more similar to an isometric contraction, which would explain the correlation between half sit-ups and isometric abdominal strength. It would be of further interest to investigate the relationship between isotonic abdominal strength (i.e., a 1RM test of spine and hip flexion) and the full sit-up exercise.

Since the half sit-up test may be included in physical fitness batteries that categorize the fitness level of an individual, the relationship between level of fitness and number of sit-ups performed was also explored. The fitness measure used for the

analysis was the subject's recovery heart rate after performing a 3-minute step test. Recovery heart rate is an indicator of aerobic fitness; commonly, the lower the heart rate the fitter the individual. A Pearson product moment correlation coefficient was computed between recovery heart rate and the number of half sit-ups performed (r=-.567, p<.001). Subjects who had lower recovery heart rates performed more half sit-ups. The correlation is moderately high, indicating a good relationship between level of fitness, as indicated by recovery heart rate, and the half sit-up test. A correlation coefficient was also computed between the number of full sit-ups performed and recovery heart rate. Although lower (r=-.399, p<.05), the correlation coefficient indicated that a relationship also existed between recovery heart rate and number of full sit-ups performed. The difference in the correlations may be explained by the near absence of full sit-ups from present exercise programs. Practicing a specific exercise carries a learning effect for its performance. Of the subjects who reported that they performed sit-up exercises regularly (65% of the subjects), only 1 was using full sit-ups, while the rest were using some variation of a half sit-up.

Since isometric abdominal strength failed to predict the performance in the sit-up tests, it was of interest to identify which variables, if any, would predict performance in the full sit-up and the half sit-up protocol. Step-wise multiple regressions were computed for that purpose. The model which best predicted

performance in the full sit-up test accounted for 45% of the variance. The variables and respective partial correlations entering the model were: cardio-respiratory endurance (.27), isometric abdominal strength (.34), percent body fat (-.66), and subject's weight (.22). This model indicated that cardio-respiratory endurance and isometric abdominal strength had a positive effect, and the body composition of subjects and their weight had an negative effect on the number of full sit-ups performed. In the case of half sit-ups, 46% of the variance was accounted for in a model including percent fat (-.42), and cardio-respiratory endurance (.38). These results indicated that cardio-respiratory endurance had a positive effect on the number of half sit-ups performed, while percent body fat had a negative effect on the number of half sit-ups performed. The results are logical for both variations of the sit-up test. Fitter subjects, both in terms of cardio-respiratory endurance and abdominal strength performed more sit-ups. On the other hand, subjects with a higher percent body fat and weight were handiccapped in the performance of the sit-up tests.

The multiple regressions also lend support to the conclusion that a large portion of the variance in the performance of the sit-up tests is accounted for by cardio-respiratory endurance. Further research should address this premise and also attempt to tease out the portion of the variance that may be accounted for by muscular endurance.

Experiment 3 - Inter-apparatus reliability

The mean half sit-ups performed on the three devices are shown in Table 8. A one-way within subjects analysis of variance (ANOVA) was computed between the number of sit-ups performed in each set. The results (F=.37, p>.05) indicate that there was no significant difference between the number of sit-ups performed between the three testing instruments. Since the order of the devices was counterbalanced, the lack of a significant difference implies that the testing instruments are interchangeable.

A Pearson product correlation matrix was computed between the number of half sit-ups performed using each device. The results are presented in Table 9. All correlations were significant and high. In addition, an intra-class reliability coefficient was computed (r=.856, p<.001). The results of this analyses also support the conclusion that the testing instruments are interchangeable.

At the end of the session, subjects were asked which device they had preferred. Apparatus A (head touches plate) was preferred by 22 of the 35 subjects (63%); Apparatus B (hands reach 3.5") was preferred by 2 of the 35 subjects (5%); and Apparatus C (switch under scapulae) was preferred by 11 of the 35 subjects (32%). Subjects reported that having a target overhead (Apparatus A) and the clear feedback of having hit (or not) that target was preferable to reaching for the Velcro tape (Apparatus B). The Velcro tape is not in direct view of the subject, although it is felt

Table 8

Inter-apparatus reliability - Means and standard deviations

Apparatus	Statistics: Mean sit-ups	SD	Minimum	Maximum
Apparatus A (head touches plate)	52.82	18.85	12	92
Apparatus B (hands reach 3.5")	49.63	15.81	21	80
Apparatus C (switched plate under scapulae)	52.54	16.51	27	85

with the fingertips. Additionally, subjects reported feeling more comfortable and "natural" when their hands were placed behind the head or across the chest while performing the half sit-ups. Apparatus A allowed the hands to be placed behind the head or across the chest, while the other two apparatuses required that the hands be pronated with the arms along the sides of the body.

This study required that the hands be pronated with arms along the side of the body, while using Apparatus C (switch under scapulae), to keep the protocols consistent. However, this apparatus allows the arms to be placed either behind the

Table 9

Inter-apparatus reliability

Correlation matrix of interapparatus coefficients

	Apparatus A	B	C
Apparatus	r	r	r
Apparatus A (head touches plate)	1.000		
Apparatus B (hands reach 3.5")	0.723	1.000	
Apparatus C (switched plate under scapulae)	0.803	0.871	1.000

All correlations significant ($p<.001$)

head or crossed over the chest. Since the plate is measuring the lift of the scapulae from the exercise surface, there is no need to assure that the fingertips slide forward 3.5 inches. That is, the reason the fingertips must slide 3.5 inches is to assure that the scapulae are being lifted from the exercise surface. If the switched plate is already measuring the lift, no further controls are needed to assure consistency while performing the half sit-up.

Table 10 shows a comparison of selected features of each apparatus. These

features were compiled from those reported by subjects, experimenters, and by personal experience. The list may aid experimenters in choosing the apparatus appropriate for their particular situation.

Table 10 - Comparison of the 3 apparatus on selected variables

Variable	Apparatus A (head touch plate)	Apparatus B (hands reach 3.5")	Apparatus C (Switch under scapulae)
Ease of construction	Somewhat involved	Very easy	Requires electrical expertise
Time of construction	3-4 hours	1 hour	3-4 hours
Material cost (approx)	$ 30.00	$ 10.00	$ 60.00
Subject preference	63%	6%	31%
Possibility of malfunction	Unlikely	None	Unlikely
Field test applicability	Very portable	Very portable	Requires power supply
Test-retest r	.939	.967	Assumed same as B
Advantages	Subjects prefer	Low cost	Easiest to administer
Disadvantages	Adjustment must be precise	Experimenter monitors scapulae, hands, and counter	Not suitable for field
	Counter may malfunction	Subjects may cheat	Bulky

Chapter 5

Summary and Conclusions

Summary

The use of full sit-ups as an exercise in physical fitness programs has declined, giving way to the abdominal crunch or half sit-up. There have been claims that the full sit-up is a controversial exercise due to the increase in lumbar curve that takes place during the initiation of the exercise, causing strain on the lower back. Individuals with a history of low-back pain probably should not perform the full sit-up exercise. It remains to be clearly shown whether the exercise is a precursor of low-back problems, or if it can be performed safely by a healthy population.

Regarding the use of the full sit-up in abdominal strength and endurance tests, the consensus is more clear. Full sit-up tests have shown poor correlations with abdominal strength and endurance. In addition, full sit-ups have been shown to recruit the hip flexor muscle group to the extent that an individual can perform well in a full sit-up test without using much of the abdominal muscle group. Fitness test batteries such as the YMCA and the ACSM include a full sit-ups test of abdominal

strength and endurance. Although the test is deemed "marginally acceptable", the lack of an alternate test of abdominal strength and endurance that shows good reliability is given as rationale for its usage. Few half sit-up tests of abdominal strength and endurance exist. The present study offered two protocols for testing abdominal strength and endurance, and tested the reliability and validity of these protocols.

Conclusions

The results of the current study yielded the following conclusions:

1. The proposed protocols for testing abdominal strength and endurance, using a 1-minute half sit-ups test, showed high test-retest reliability (.97 and .94). The test was therefore deemed a reliable test across testing sessions.

2. The 1-minute half sit-ups test showed moderately high concurrent validity (.69), indicating a moderate relationship with the 1-minute full sit-ups test.

3. The 1-minute half sit-ups test showed a moderate relationship with isometric abdominal strength (.44). Since abdominal strength and endurance are coupled, it is assumed that the variance unaccounted for by abdominal strength, may be due to muscular endurance and to cardiorespiratory fitness. The 1-minute half sit-ups test showed a moderately high correlation with cardiorespiratory fitness (.57).

4. There were no significant differences between the number of sit-ups performed using three different testing instruments designed for measuring the effectiveness of

half sit-up protocols. The criteria used for two of the devices (A and C) for performing a half sit-up, was that the inferior angles of the scapulae were lifted off the exercise surface. The third apparatus (B) used the criteria that the fingertips be slid forward 3.5", regardless of the degree of scapula lift.

Recommendations

Based on the findings of the current studt, the following recommendations are offered:

1. The 1-minute half sit-ups test is recommended for implementation as a test of abdominal strength and endurance, due to its high reliability and validity. The preferred test was the test requiring the subject to touch the head to a plate, since this practice gave the subject feedback regarding the amount of "curl" needed to perform a "correct" half sit-up.

2. The recommended criteria for determining a half sit-up is that the angles of the scapulae be lifted from the exercise surface. The reach-3.5" test does not use this criteria directly, but for the majority of subjects it is interchangeable with the other tests (excluding subjects with very poor spine flexibility). Reaching a certain distance with the fingertips may favor those with good shoulder flexibility, and handicap those with poor spine flexibility.

3. The reach-3.5" test is recommended for mass testing or when expense of equipment

is a concern, since all that is required is Velcro tape. Use of masking tape or similar is not recommended, since the subject may have trouble feeling the landmark. Use of a rigid landmark such as wood may cause some subjects to hold back for fear of jamming the fingers against the landmark.

The head-touch test is only slightly more expensive, several apparatuses can be constructed easily for group testing, and it uses the preferred criteria for determining a half sit-up. In addition, this apparatus was preferred by most subjects. The counter can be omitted from the apparatus and the experimenter can simply count the number of times the head of the subject touches the pad. The switched plate apparatus is recommended for laboratory testing, although expense and portability are a problem. This apparatus allows self testing.

4. Further research could address the problem of strength and endurance tests. There is a need to determine to what extent strength and endurance tests are measuring strength, endurance, and other variables such as cardiorespiratory fitness. Better tests of muscular strength and endurance could be designed once the magnitude of each variable can be determined, if in fact the variables can be separated.

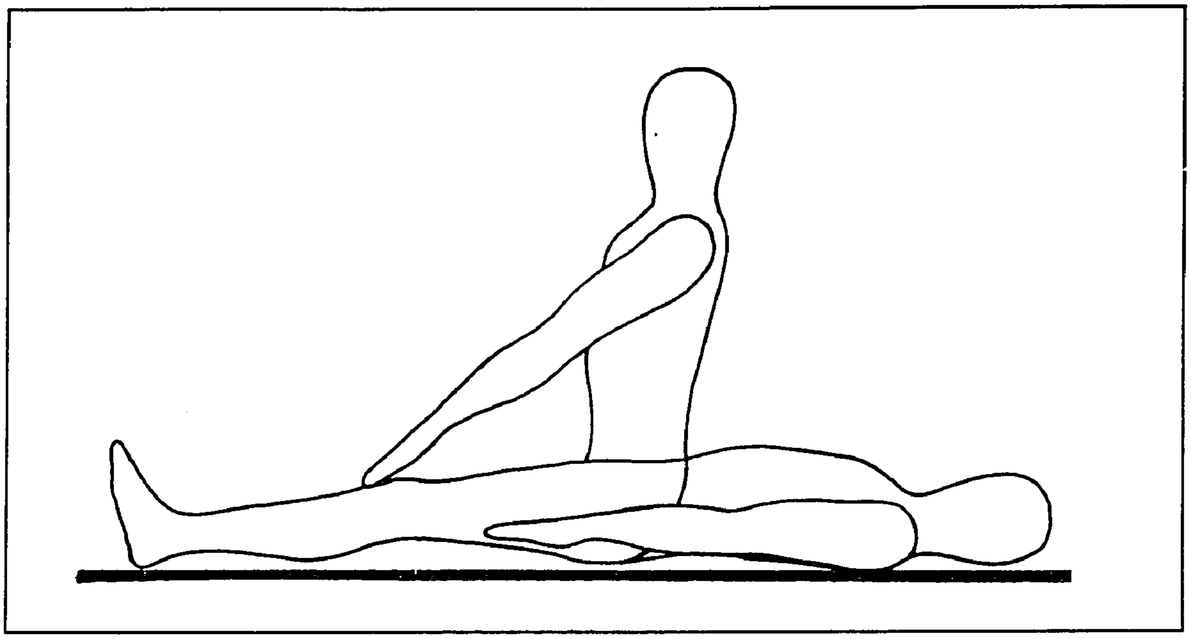
5. An EMG study could be designed to record the activity of the abdominal muscles up to the point where the scapulae lift from the exercise surface, using the protocols described in the present study. This would serve to support the findings of this study,

and the use of the inferior angles of the scapulae as the desired landmark.

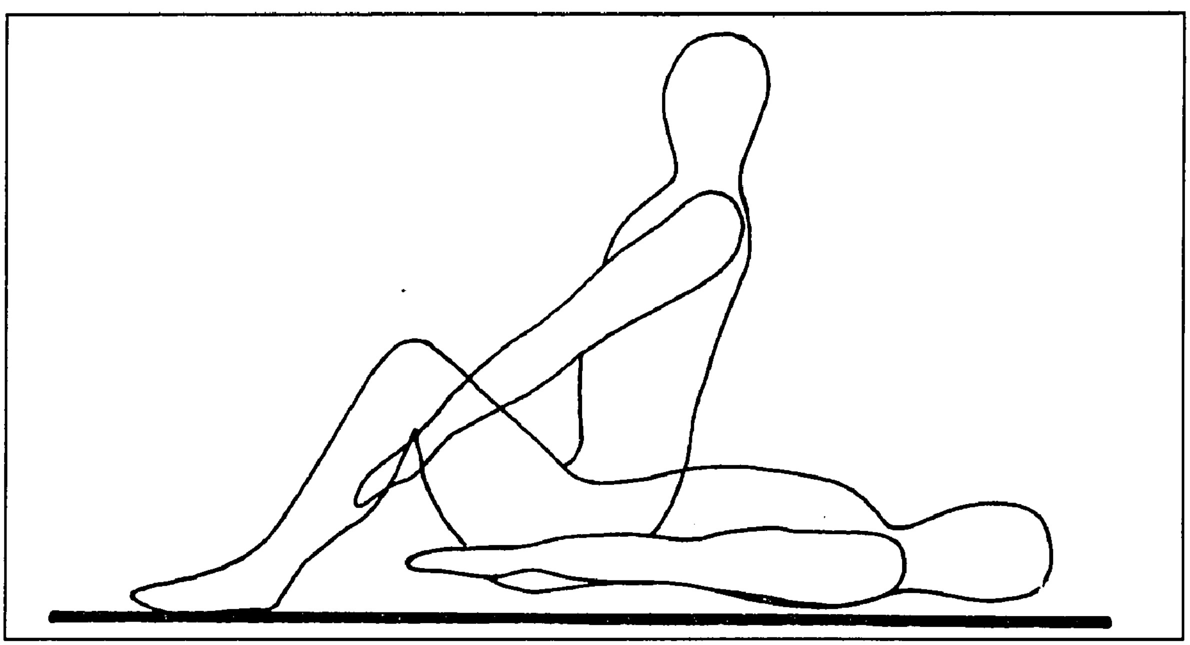
6. Normative values need to be collected on the half sit-up protocol for the population to allow for comparison among individuals.

Appendix A

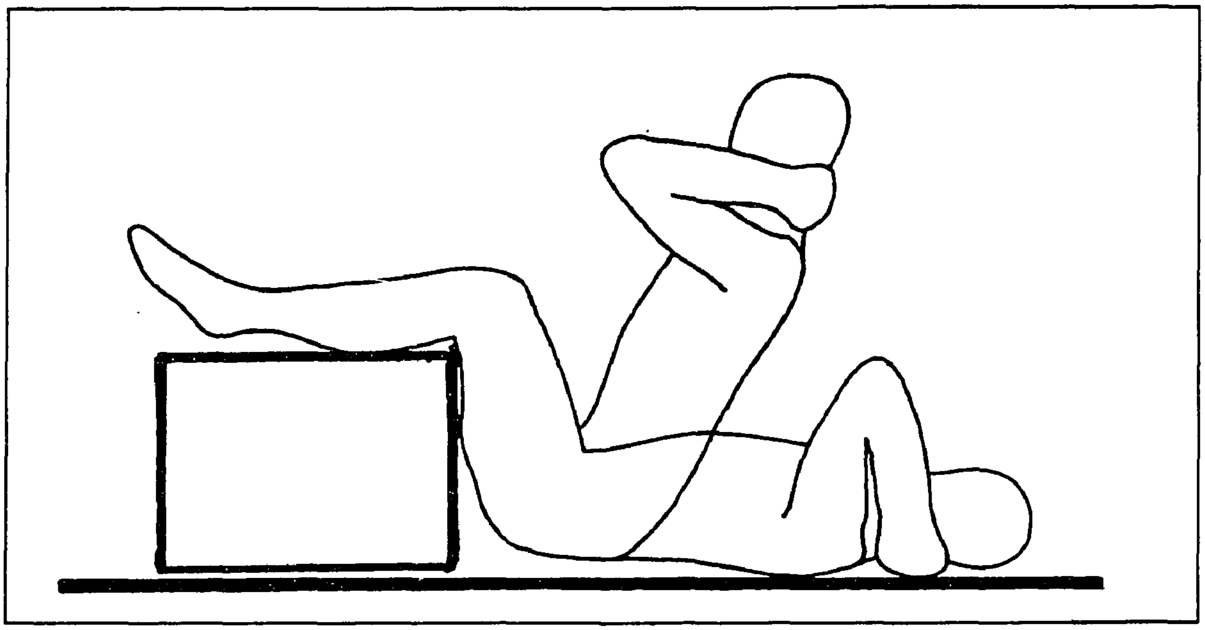
Selected sit-up variations



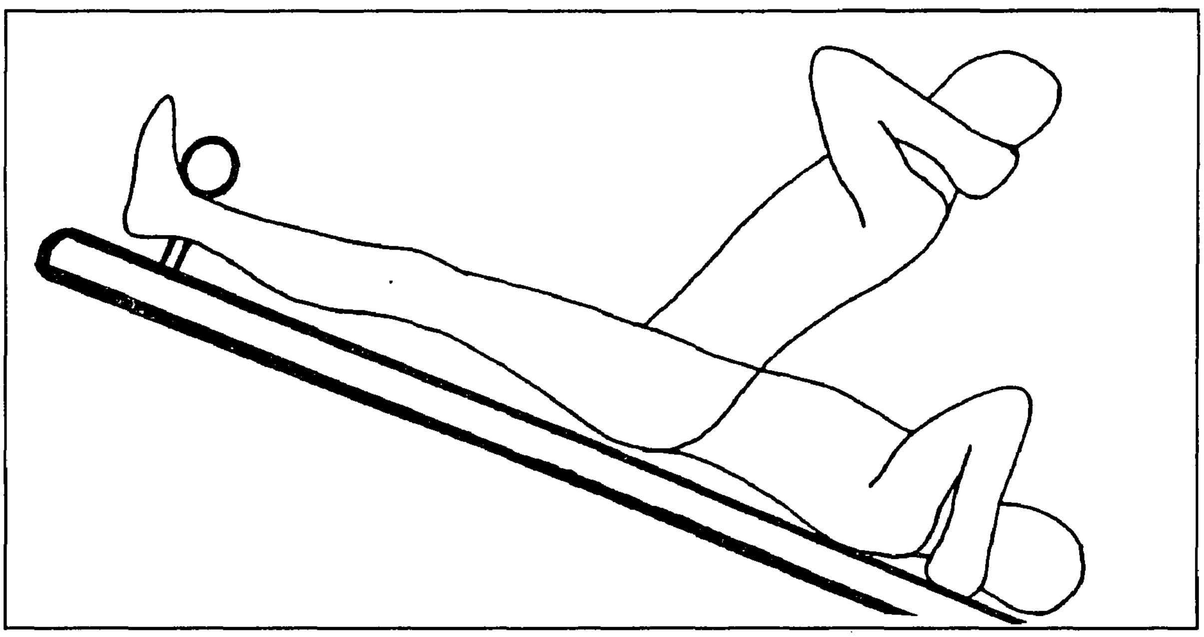
1. Conventional full sit-up



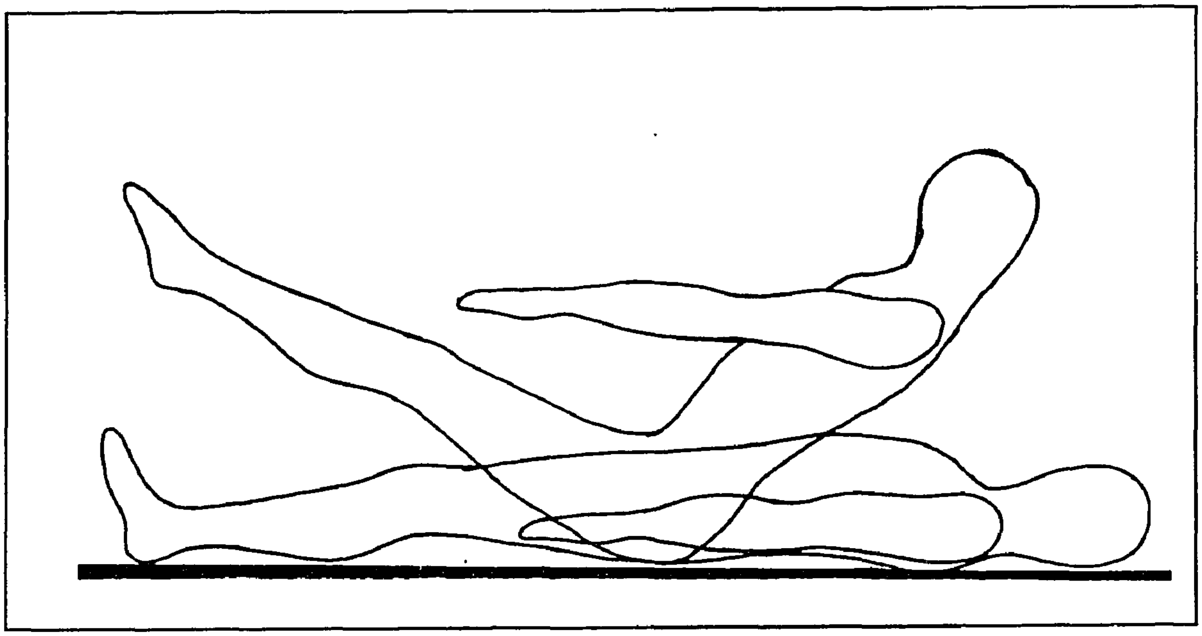
2. Conventional hook lying full sit-up



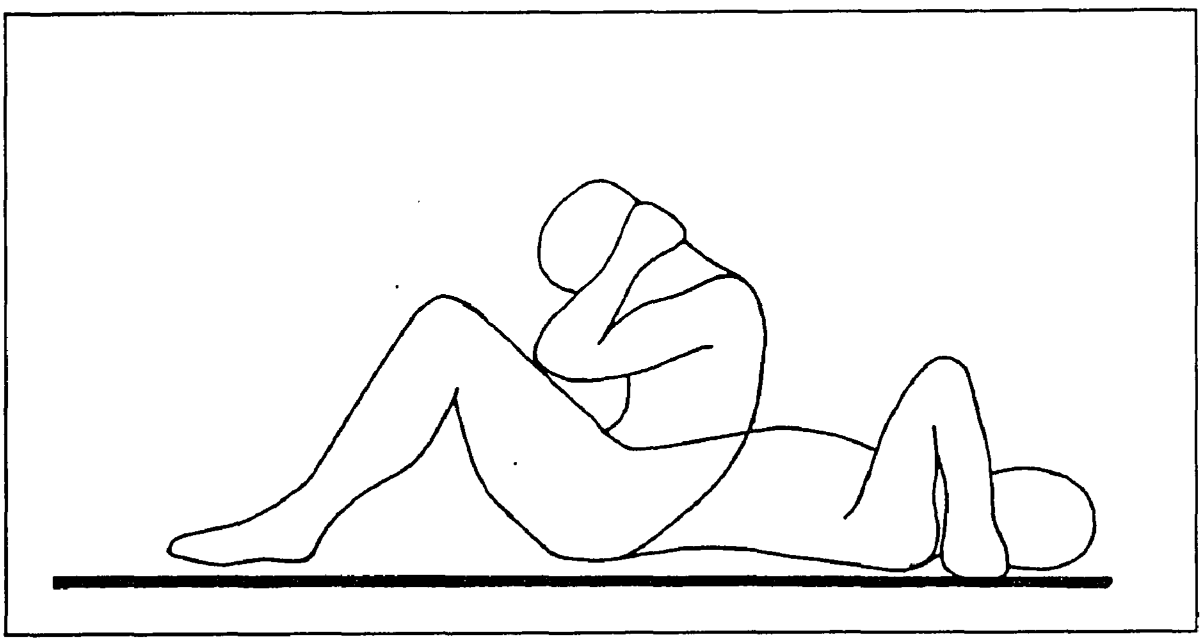
3. Modified hook full sit-up



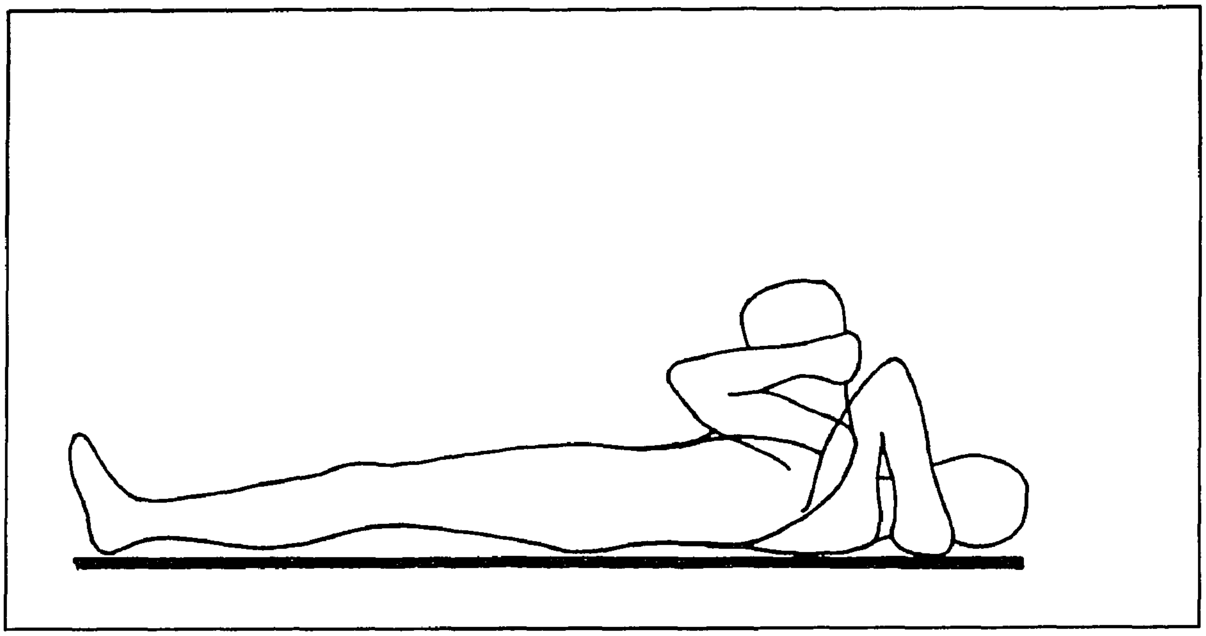
4. Incline full sit-up



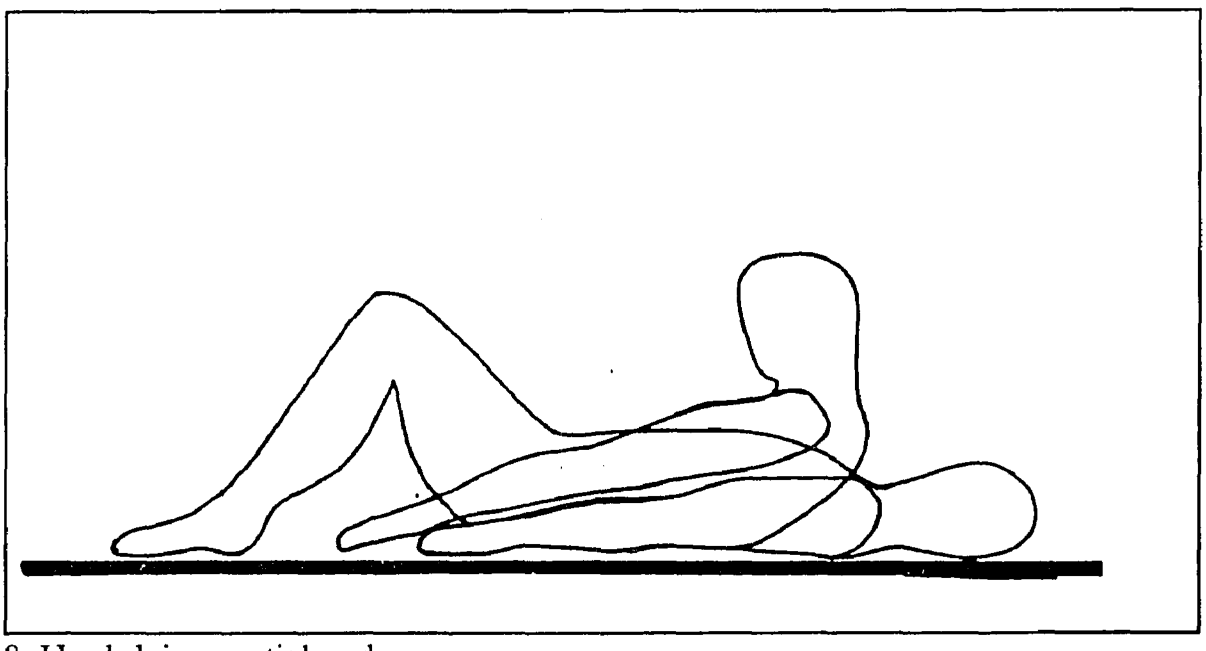
5. V-sit



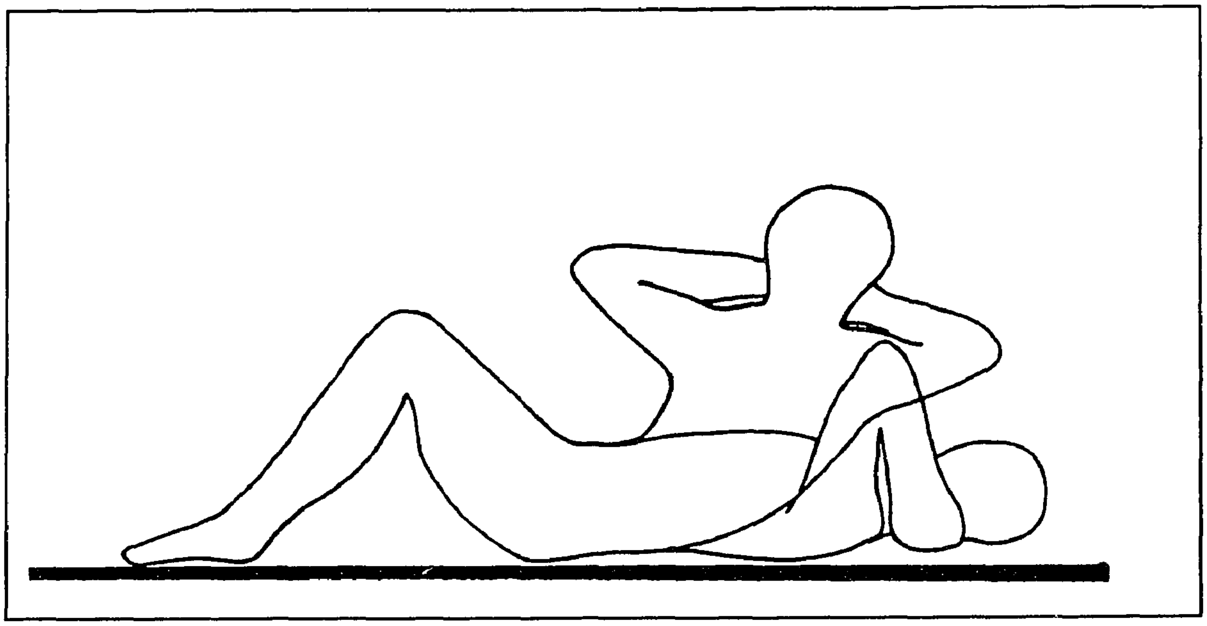
6. Full curl-up



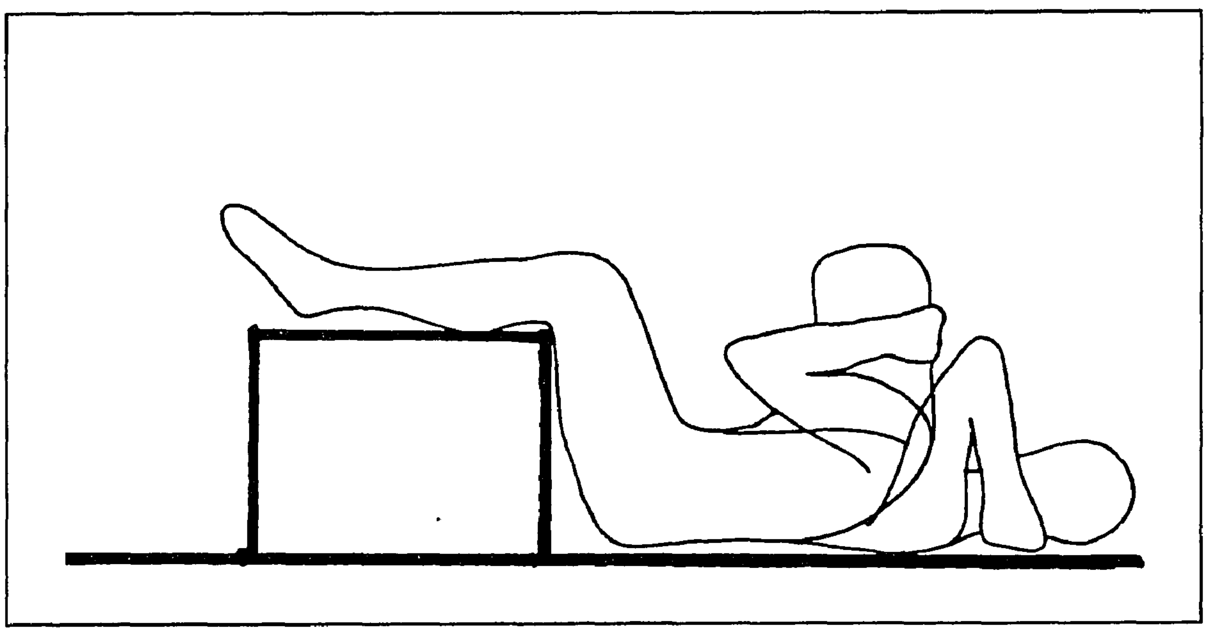
7. Conventional partial curl-up (half sit-up)



8. Hook-lying partial curl-up



9. Partial curl-up with trunk twist



10. Modified hook-lying curl-up

Appendix B

Consent form

UNIVERSITY OF NEVADA, LAS VEGAS
4505 Maryland Pkwy. Las Vegas, NV 89154

Exercise Physiology Laboratory
School of Health, Physical Education, and Recreation

INFORMED CONSENT

Title of Study:
The Reliability of a Timed 1-minute Half Sit-ups Test

You have volunteered to participate in a study which involves performing half sit-ups for one minute in two separate occasions. You will participate in one session, lasting approximately 30 minutes. All the procedures will be explained to you prior to the tests.

The testing will go as follows: 4 skinfold measurements will be taken (abdomen, hip, triceps, and thigh) to determine percent body fat. A flexibility test will be administered in which you will reach with your hands as far as you can in front of you while in a sitting position. A 3-minute step test will be administered consisting of stepping up and down on a 12" bench at a rate of 24 steps per minute. After 3 minutes recovery heart rate will be taken for 1 minute. The score will classify aerobic fitness. Abdominal strength will be tested by use of a strength table. You will be asked to do as many half sit-ups as you can in one minute, in two separate occasions during the test session. The order of the above tests may be altered, however, all the tests will be administered. You will be allowed to rest briefly between tests. At the end of the session, you will receive a fitness evaluation.

You are free to withdraw consent and discontinue participation in the study at any time. If, during the project you are unsure about any phase of the project, feel free to ask the experimenter for clarification. The experiment requires that you perform sit-ups as fast as you can, which may result in muscle soreness or shortness of breath. In addition, full sit-ups have been known to cause lower back strain in individuals with low-back problems. If at <u>any time</u> you experience any pain or discomfort which prevents you from continuing, you may terminate the test.

This study investigates the performance of a group, and not individual performance. Therefore your identity will not be associated with the data that you generate. All results will be kept confidential and remain the property of the Exercise Physiology Laboratory at the University of Nevada, Las Vegas.

YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE IN THE STUDY, THAT YOU HAVE READ THE INFORMATION PROVIDED ABOVE, AND THAT ANY QUESTIONS ABOUT THE EXPERIMENT, HAVE BEEN ANSWERED TO YOUR SATISFACTION

Date	Signature of Participant	Print Name
Date	Signature of Witness	Print Name

Appendix C

Questionnaire

Par-Q

UNIVERSITY OF NEVADA, LAS VEGAS

EXERCISE PHYSIOLOGY LAB

Validity of the 1-minute partial curl-up test — SUBJECT [ ]

1. Age [ ] 2. Height [ ] 3. Weight [ ]

Exercise habits:

4. I exercise
   - 5 or more times per week [ ]
   - 3 or 4 times per week [ ]
   - 1 or 2 times per week [ ]
   - once in a while [ ]
   - not at all [ ]

5. I do sit-ups
   - on a regular basis [ ]
   - once in a while [ ]
   - in the past, but not now [ ]
   - never done sit-ups [ ]

6. I have lower back trouble
   - often [ ]
   - once in a while [ ]
   - in the past [ ]
   - never bothered me [ ]

7. I have been treated for lower back trouble in the past
   - YES [ ]
   - NO [ ]

8. I am currently on medication for lower back pain
   - YES [ ]
   - NO [ ]

Physical Activity Readiness Questionnaire (PAR-Q)*

PARTICIPANT IDENTIFICATION

PAR Q & YOU

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read them carefully and check (✓) the ☐ YES or ☐ NO opposite the question if it applies to you.

YES	NO	
☐	☐	1. Has your doctor ever said you have heart trouble?
☐	☐	2. Do you frequently have pains in your heart and chest?
☐	☐	3. Do you often feel faint or have spells of severe dizziness?
☐	☐	4. Has a doctor ever said your blood pressure was too high?
☐	☐	5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
☐	☐	6. Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
☐	☐	7. Are you over age 65 and not accustomed to vigorous exercise?

If You Answered

YES to one or more questions

If you have not recently done so, consult with your personal physician by telephone or in person BEFORE increasing your physical activity and/or taking a fitness test. Tell him what questions you answered YES on PAR-Q, or show him your copy.

programs

After medical evaluation, seek advice from your physician as to your suitability for:

- unrestricted physical activity, probably on a gradually increasing basis.
- restricted or supervised activity to meet your specific needs, at least on an initial basis. Check in your community for special programs or services.

NO to all questions

If you answered PAR-Q accurately, you have reasonable assurance of your present suitability for:

- A GRADUATED EXERCISE PROGRAM - A gradual increase in proper exercise promotes good fitness development while minimizing or eliminating discomfort.
- AN EXERCISE TEST - Simple tests of fitness (such as the Canadian Home Fitness Test) or more complex types may be undertaken if you so desire.

postpone

If you have a temporary minor illness, such as a common cold.

* Developed by the British Columbia Ministry of Health. Conceptualized and critiqued by the Multidisciplinary Advisory Board on Exercise (MABE). Translation, reproduction and use in its entirety is encouraged. Modifications by written permission only. Not to be used for commercial advertising in order to solicit business from the public.
Reference: PAR-Q Validation Report, British Columbia Ministry of Health, 1978.
* Produced by the British Columbia Ministry of Health and the Department of National Health & Welfare.

Appendix D

Subject results and information form

YMCA's fitness profile form

UNIVERSITY OF NEVADA, LAS VEGAS / EXERCISE PHYSIOLOGY LABORATORY

THANK YOU FOR PARTICIPATING IN THIS STUDY!

Body Composition

A body composition profile is an important part of most physical fitness test batteries because it is generally accepted that a lean body performs better, looks better and is less of a health risk than an overweight body.

Your body is made up of lean body weight (bones, muscles, organs) and fat weight. Fat weight is divided into structural (essential) fat and storage fat. Storage fat results from excess calories eaten. Much of this is deposited directly below the skin and above the muscle. This storage fat is what the calipers measure.

The average % fat is what the average population measures. However, average does not necessarily mean desirable! The average and desirable norms for the population are listed below.

% FAT NORMS

Average FEMALE	25 % fat	Desirable	19-23 % fat
Average MALE	19 % fat	Desirable	16-19 % fat

YOUR TOTAL BODY WEIGHT ________ PERCENT (%) BODY FAT ________
YOUR RECOMMENDED WEIGHT ________ POUNDS TO LOSE ________

To affect a positive change in your body composition it is recommended that you increase the amount of regular exercise. If weight reduction is your goal, you can also decrease your caloric intake by reducing the amount of fat in your diet.

Flexibility

Flexibility may be defined as the capacity to move a limb or body part through its range of motion. Since flexibility is essentially joint specific, a fitness program should emphasize good range of motion in all the joints.

Flexibility is easy to increase and maintain at any age, but is also rapidly lost through sedentary living or physical inactivity. Good flexibility has been related to reduced injuries, good posture, decreased low back pain and good physical performance.

YOUR SCORE ________

To improve your flexibility, stretching of the joints throughout their range of motion frequently is recommended. You should not feel pain, but should gently stretch muscles. NEVER use a bouncing or fast motion for stretching.

Abdominal Strength and Endurance

Abdominal strength and endurance is also beneficial for good posture. Weak abdominal muscles, in combination with being overweight around the mid-section, are associated with strain on the lower back. Good abdominal muscle tone, achieved by strengthening the abdominal muscle group, is a desired physical asset. The sit-ups test is a good assessment of abdominal strength and endurance.

YOUR SCORE ________

To increase strength in any muscle, an overload is necessary. Although weight lifting is the usual exercise associated with strength building, calisthenics, or exercises in which the body itself is used as resistance, are more available and require no equipment.

Calisthenic exercises include sit-ups (or crunches), push-ups, leg lifts, half-squats, arm circling, hopping in place, and many others. In addition to improving your strength, calisthenic exercises can also help your flexibility and even positively affect your body composition.

Aerobic Fitness

Aerobic fitness can be measured by recovery heart rate, or how long it takes your heart to recover after a bout of exercise. Aerobic fitness goes hand in hand with cardiovascular health. People who perform aerobic exercise regularly have less risk of cardiovascular disease. The 3 minute step test is a good measure of fitness.

YOUR SCORE ____________

To increase your aerobic fitness, you guessed it!, aerobic exercise. This does not mean aerobic dance!!. Aerobic exercise is any exercise that you can maintain for a period of time at a moderate rate. This includes walking, swimming, jogging, bicycling, and climbing stairs, among many others. The secret is to enjoy it enough so that your exercise sessions are repeated often.

The American College of Sports Medicine (ACSM) recommends the following guidelines for improvement and maintenance of cardiorespiratory endurance:

EXERCISE 3-6 TIMES PER WEEK
30-60 MINUTES EACH TIME
60-85 % OF MAXIMUM HEART RATE

Your maximum heart rate is estimated by the formula "220-age". A good rule of thumb is to exercise at a pace you can maintain for at least 30 minutes. Improvement comes fast with persistence, and wellness benefits are waiting!

The next page is a fitness profile on some of the tests that you participated in, and the National YMCA norms for people your sex and age. This gives you a good idea of how you compare with the average population.

If you have any questions about your performance on this tests, their meaning, or any topics related to exercise, please feel free to contact me at 597-4102. Thank you again.

Maria H. Diener

Y's Way to Physical Fitness

Physical Fitness Evaluation Profile

Norms—Women 18-25

Name ______________________ Dates: T1 ________ T2 ________ T3 ________

Rating	% ranking	Resting HR	% fat	3-min step test	PWC max (kgm)	$\dot{V}O_2$max (mL/kg)	Flexibility	Bench press	Sit-ups
Excellent	100 95 90	54 56 60	13 15 17	72 79 83	1830 1640 1440	71 67 58	27 25 24	50 42 36	56 48 44
Good	85 80 75	61 64 65	18 19 20	88 93 97	1320 1235 1175	54 50 48	23 22 21	32 29 28	41 38 37
Above average	70 65 60	66 68 69	21 22 23	100 103 106	1120 1075 1030	46 43 42	21 20 20	25 24 22	36 34 33
Average	55 50 45	70 72 73	24 25 25	110 112 116	990 950 915	41 40 39	19 19 18	21 20 18	32 30 29
Below average	40 35 30	74 76 78	26 27 28	118 122 124	880 845 810	37 35 34	18 17 17	16 14 13	28 26 25
Poor	25 20 15	80 82 84	29 30 31	128 133 137	775 740 705	32 31 29	16 15 14	12 9 8	24 22 20
Very poor	10 5 0	86 90 100	33 37 43	142 148 155	640 555 500	28 22 18	13 12 8	5 2 1	17 10 4

Actual Scores									
	T1	____	____	____	____	____	____	____	____
	T2	____	____	____	____	____	____	____	____
	T3	____	____	____	____	____	____	____	____

	T1	T2	T3
Actual Weight	________	________	________
Target Weight	________	________	________
Blood Pressure	____/____	____/____	____/____

Your actual weight should be within 10% of your target weight. If your blood pressure exceeds 150/90 it is considered high. Your YMCA Medical Advisory Committee should have guidelines for when blood pressure is too high to continue fitness testing.

Appendix E

Materials and instructions for Apparatus A

Appendix E - Materials and Instructions for Apparatus A

Materials

-Sportline Tally Lap Counter

-1 1/2" (diameter) PVC pipe, approximately 80 inches

-2 each 1 1/2" T-connectors

-1 each 1 1/2" 90 degree elbow

-1 each 1 1/2" 45 degree elbow

-2 eye bolts with nuts (2 1/2" x 3/8")

-1 flange, threaded, 1 1/2"

-1 male-male threaded pipe connector, 1 1/2"

-1 female threaded PVC end connector, 1 1/2"

-Scrap wood for the base, approximately 30" x 24"

-1 small (3" x 3") square of clear plastic

-Neoprene or similar padding (3" x 3")

-12" of Velcro, self-stick

-Sprinkler pipe cement

Instructions

(Refer to Illustrations)

-The base of the apparatus was constructed from a rectangle of 3/4" plywood (24" x

30").

-A 1 1/2" threaded lead pipe flange was secured to the base with wood screws.

-A 1 1/2" x 2" threaded pipe connector (male/male) was threaded onto the flange.

-A female standard sprinkler PVC 1 1/2" threaded connector was threaded onto the assembly.

-A 36" x 1 1/2" standard PVC sprinkler pipe (white) was cemented with PVC cement to the connector. Thirty 3/8" holes were drilled through the diameter of the pipe at 3/4" intervals. The pipe was placed in the connector so that the holes were perpendicular to the front and back of the rectangular base. This arm of the apparatus was called the *upright.*

-A 1 1/2" PVC T-connector was hollowed with a round file, so that it could slide freely on the upright. Two holes were drilled through the diameter of the T-connector 1" apart, so that when the T-connector was fitted on upright, the holes coincided with the holes in the upright. The T-connector's free arm was placed facing away from the rectangular base.

-Two 2 1/2" x 3/8" eyebolts were fitted through the holes in the T-connector and the upright, and secured with 3/8" wingnuts.

-A 22" x 1 1/2" PVC sprinkler pipe was cemented to the free arm of the T-connector. This arm was called the *movable arm.*

-A 1 1/2" 90° PVC sprinkler elbow connector was cemented to the movable arm so that the free arm of the elbow faced to the ground.

-A 1 1/2" x 3" PVC sprinkler pipe was cemented to the elbow connector.

-A 1 1/2" 45° PVC sprinkler elbow connector was cemented to the previous pipe so that the free arm of the elbow faced directly towards the rectangular base. A small piece of pipe was cemented to the elbow (approximately 2") so that the last T-connector could be attached.

-A 1 1/2" T-connector was cut with a hacksaw lengthwise, leaving approximately 3/4 of the full circle intact, and leaving a cut-out area of 1". The arms of the T-connector were cut to about an inch on each side. The T-connector was cemented to the previous assembly, with th^Xxcut-out area facing the rectangular base, and the arms of the connector parallel to the ground.

-A 1/8" hole was drilled through the center of the push lever of a standard manual lap counter. A 1/8" hole was also drilled in the center of a 3" x 3" piece of clear plexi-glass (1/16" thick) and was attached to the lever with a 1/8" small screw. This piece was named the *contact plate.*

-A 3 1/4" x 3 1/4" neoprene pad was attached to the contact plate with hook and stick tape (Velcro), so that the pad overlapped the plate. The tape was cut out so that the readout on the lap counter was visible without disassembling the contact plate.

-The lap counter with the contact plate attached, was inserted inside the cut-out T-connector. The counter fit snugly inside the connector so that no adhesives were necessary. The contact plate faced the rectangular base, and the lap counter readout was visible by detaching the pad from the plate.

-A 30° wooden wedge was constructed by assembling 3 pieces of 2" x 2" lumber of approximately 15", 20", and 25" to form two triangles (30° x 45° x 90°). The wood was glued with carpenters glue and nailed. The two triangles were joined by attaching a 25" x 15" sheet of hard board (masonite), with carpenters glue. The assembly was named the *wedge*.

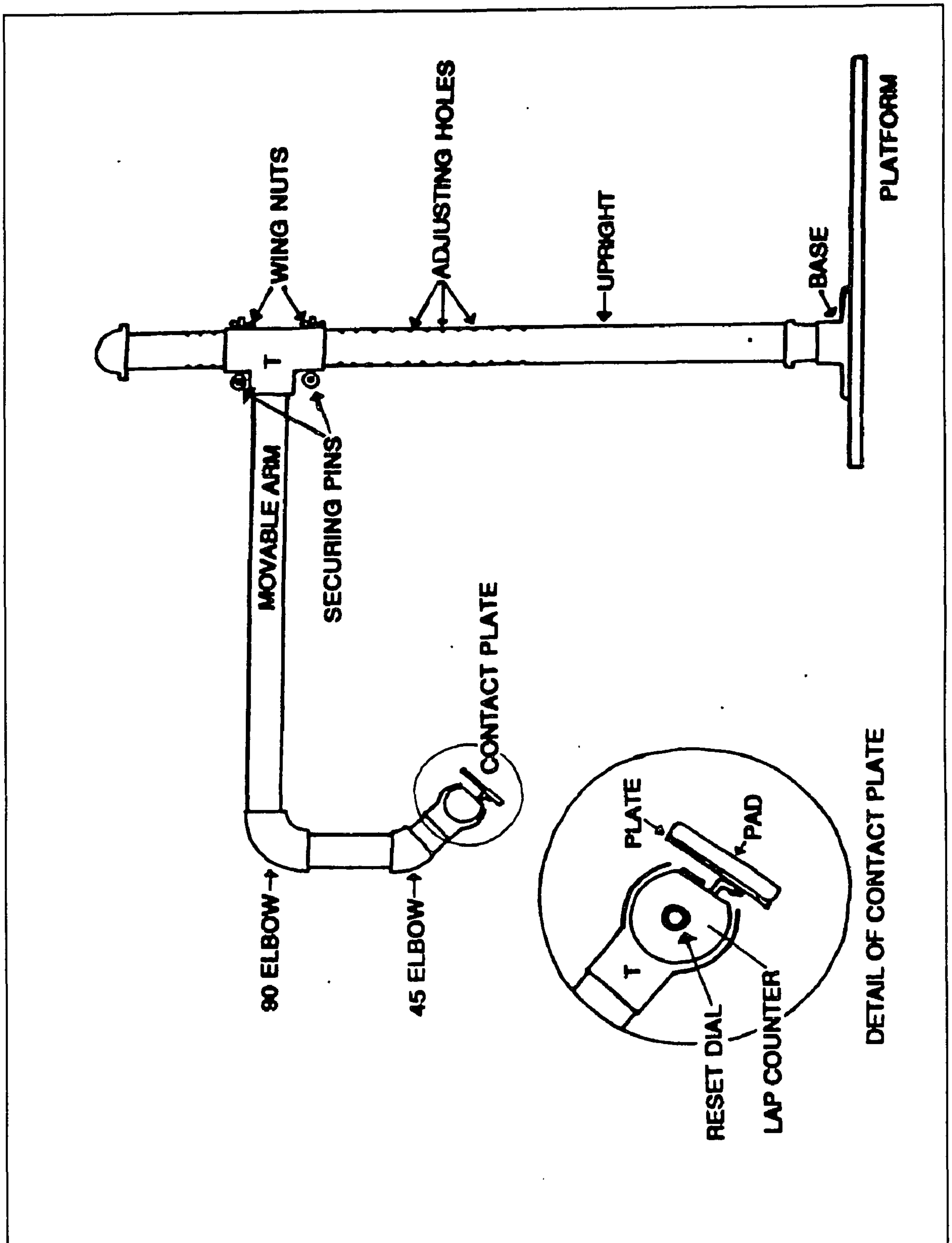


Illustration 1 - Construction guide for Apparatus A

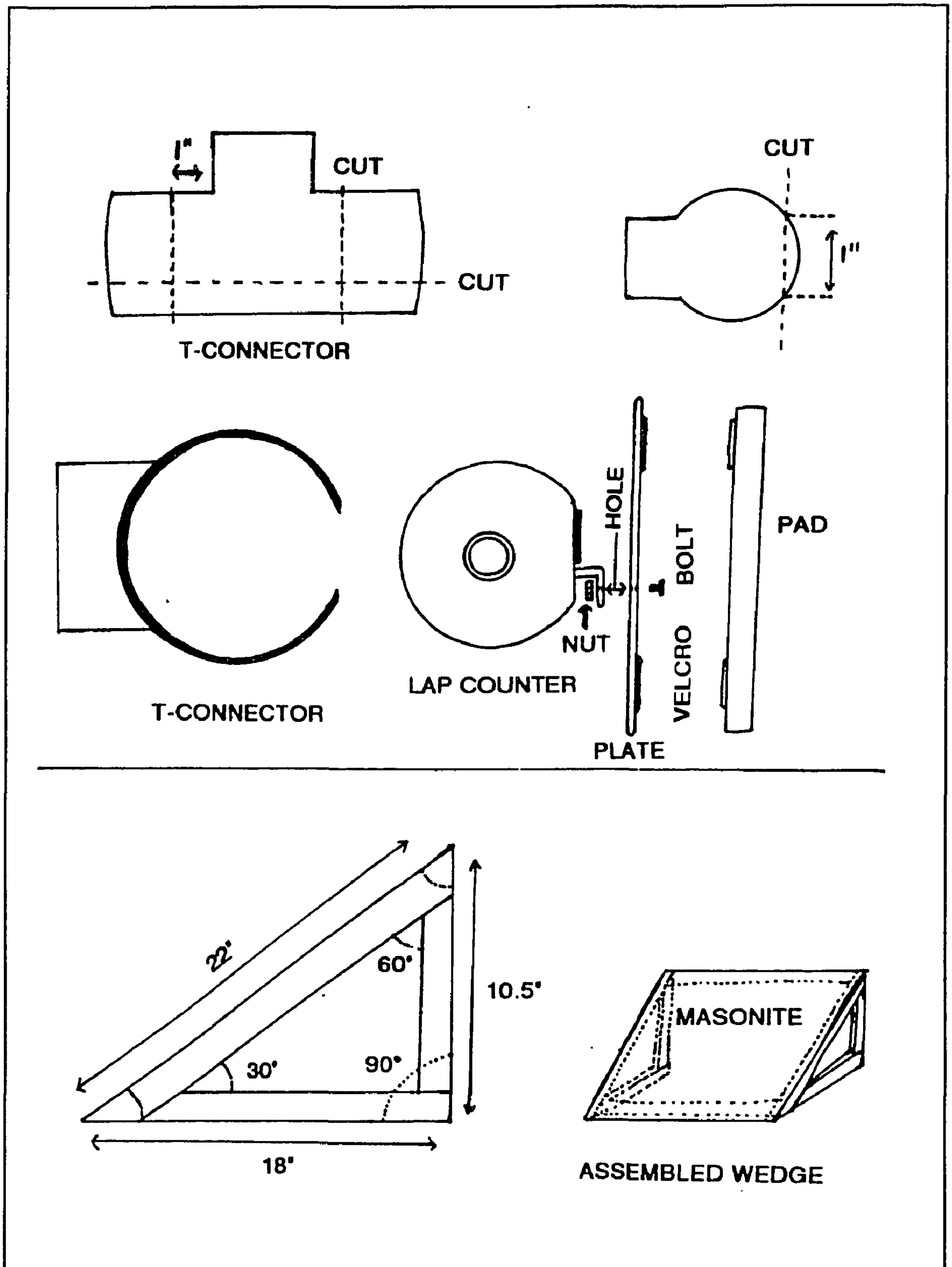
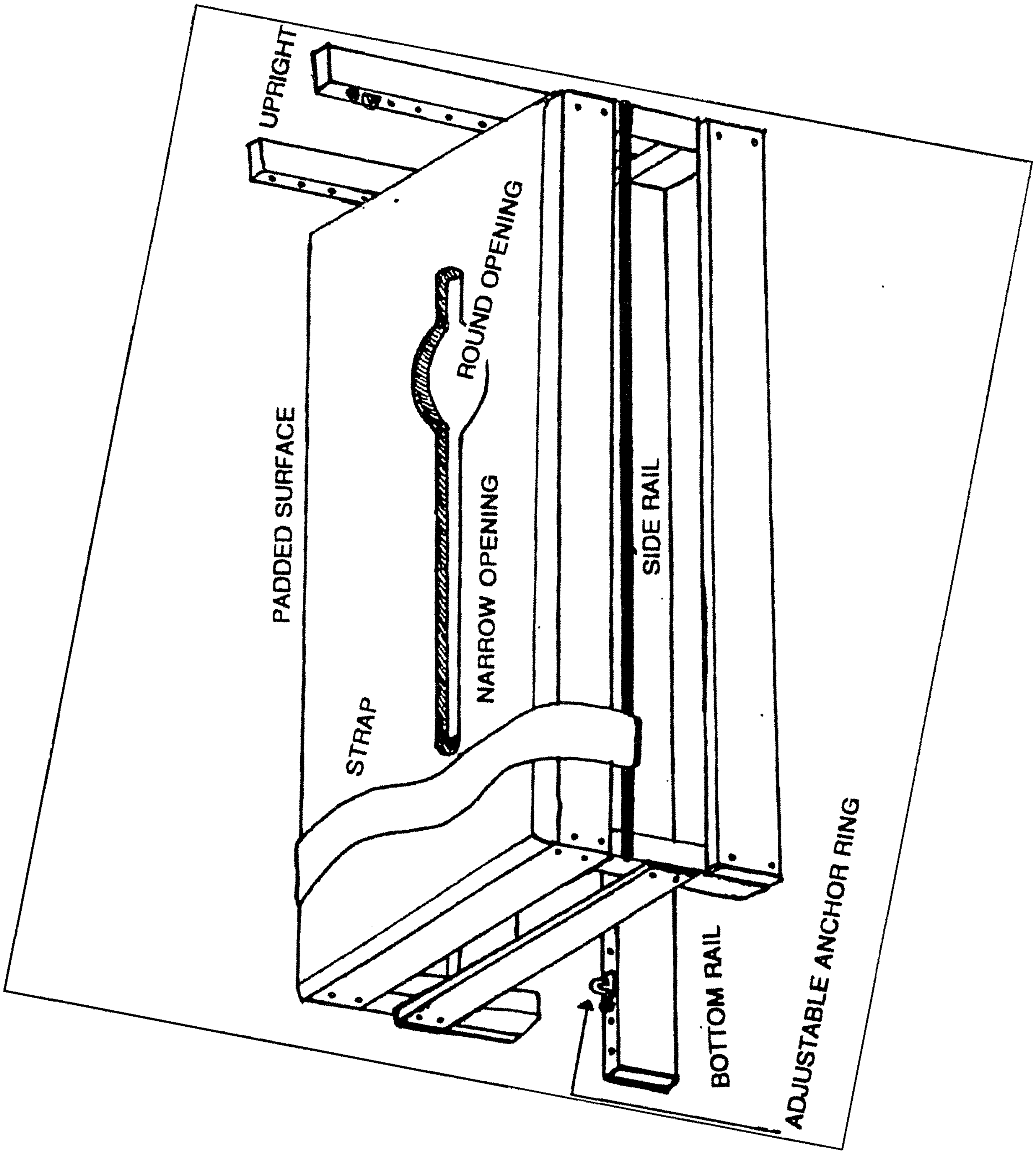


Illustration 2 - Detail of contact plate and wedge for Apparatus A

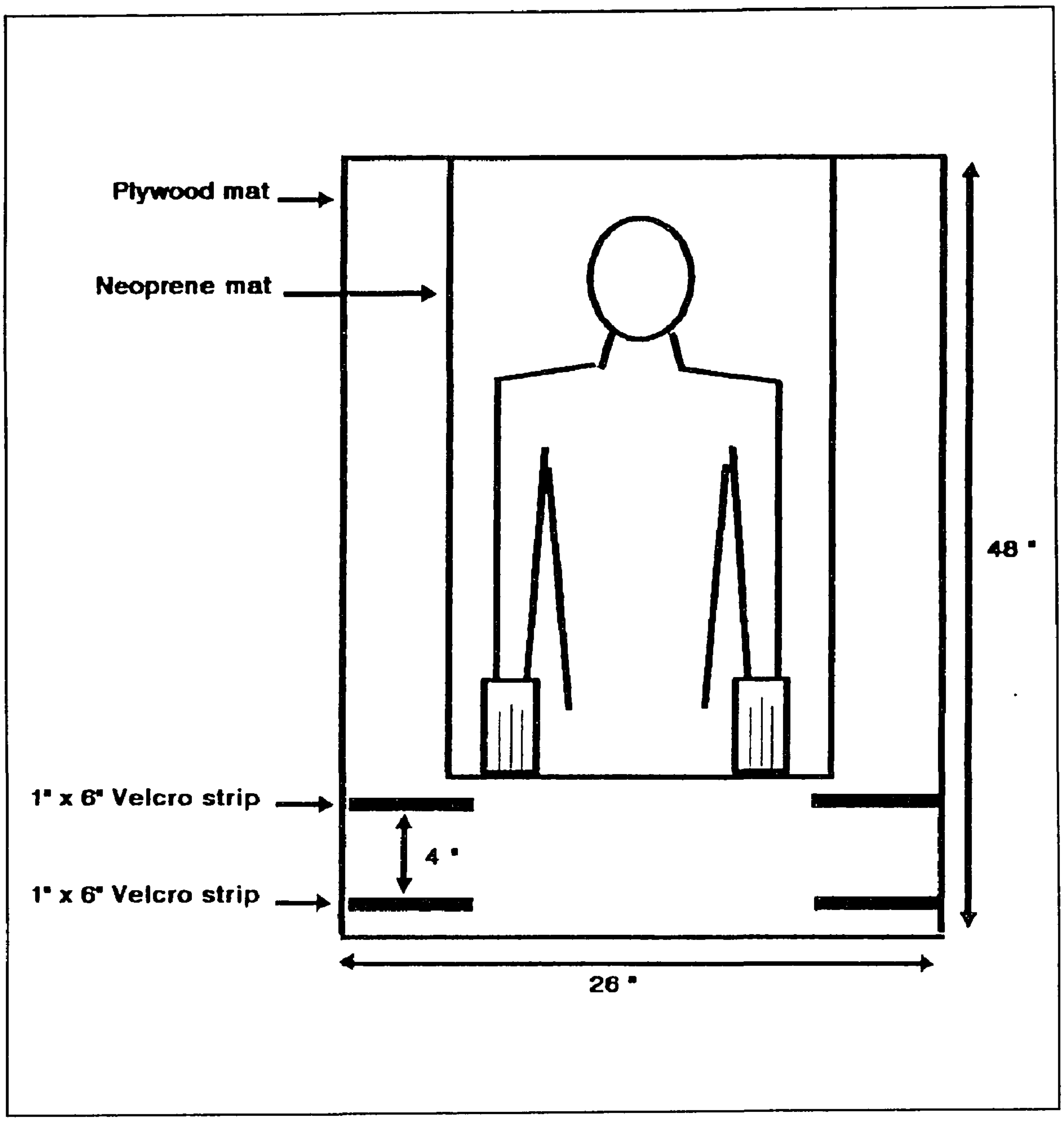
Appendix F

Strength table



Appendix G

Apparatus B



Appendix H

Materials and instructions for Apparatus C

Appendix H - Materials and Instructions for Apparatus C

Materials

-A 5/8" x 74" x 30" plywood board

-1" x 60" hook and stick (Velcro) tape, self-stick

-A 30" x 22" masonite board

-A cassette recorder remote foot switch (Realistic brand)

-An electromechanical counting module, 12V DC, with 5 digit counting display and pushbutton reset (Archer brand)

-2 1/8" (3.5mm) phone jacks

-1 phono plug to 1/8" phone plug adapter

-An experimenter box 6 1/4"L x 3 3/4"D

-An AC power adapter, 12Volts, 500 miliamps, DC output

Instructions

(Refer to Illustration)

-A hole was cut in the plywood board parallel to the length of the board, large enough to accommodate the pedal switch (approximately 15" x 3 1/2"). The purpose of this narrow opening was to be able to adjust the position of the pedal switch directly under the angles of the scapulae of the subject, by sliding the switch along the opening.

-A cutout was made with a router from the hole through the length of the board, to accommodate the wire of the pedal switch to the counter. Once the pedal switch was set in the hole, the wire was placed in the routed opening and taped over with duct tape to protect it from being torn.

-The electromechanical counter was attached to the experimenter's box so that the display could be viewed from the top of the box. A small cutout on the box was made for this purpose.

-The phone plugs were attached to the side of the experimenters box; one was used to plug in the pedal switch, the other to plug in the 12V AC adapter. The mechanical counter was wired to the pedal switch, by soldering to one phone plug. The counter was also wired to the power supply by soldering to the other phone plug. The circuit is pictured in the instructions included with the electromagnetic counter.

-The experimenter's box was attached to the plyboard with Velcro, to allow for easy removal for transport.

-The masonite board was fitted with two strips of Velcro (approximately 15" each). The Velcro was placed along the short sides, approximately 6" from the edges.

-The mate of the strips of Velcro was attached to the plyboard, at the same distance from the edges, and at both sides of the narrow opening. The switch was attached,

also with Velcro, to the masonite board directly in the center. By placing the masonite board, switch side down onto the plyboard, the switch could be adjusted the length of the Velcro, to accommodate subjects of different sizes. Once the switch was in place, the Velcro kept it from being displaced.

-A small piece of neoprene mat was placed on the up side of the masonite board to allow the experimenter to know exactly the position of the switch.

-Two 6" strips of Velcro were placed 4" apart perpendicular to the length of the plyboard, approximately 22" from the bottom edge of the board. These were used to follow the same half sit-ups protocol followed with Apparatus B.

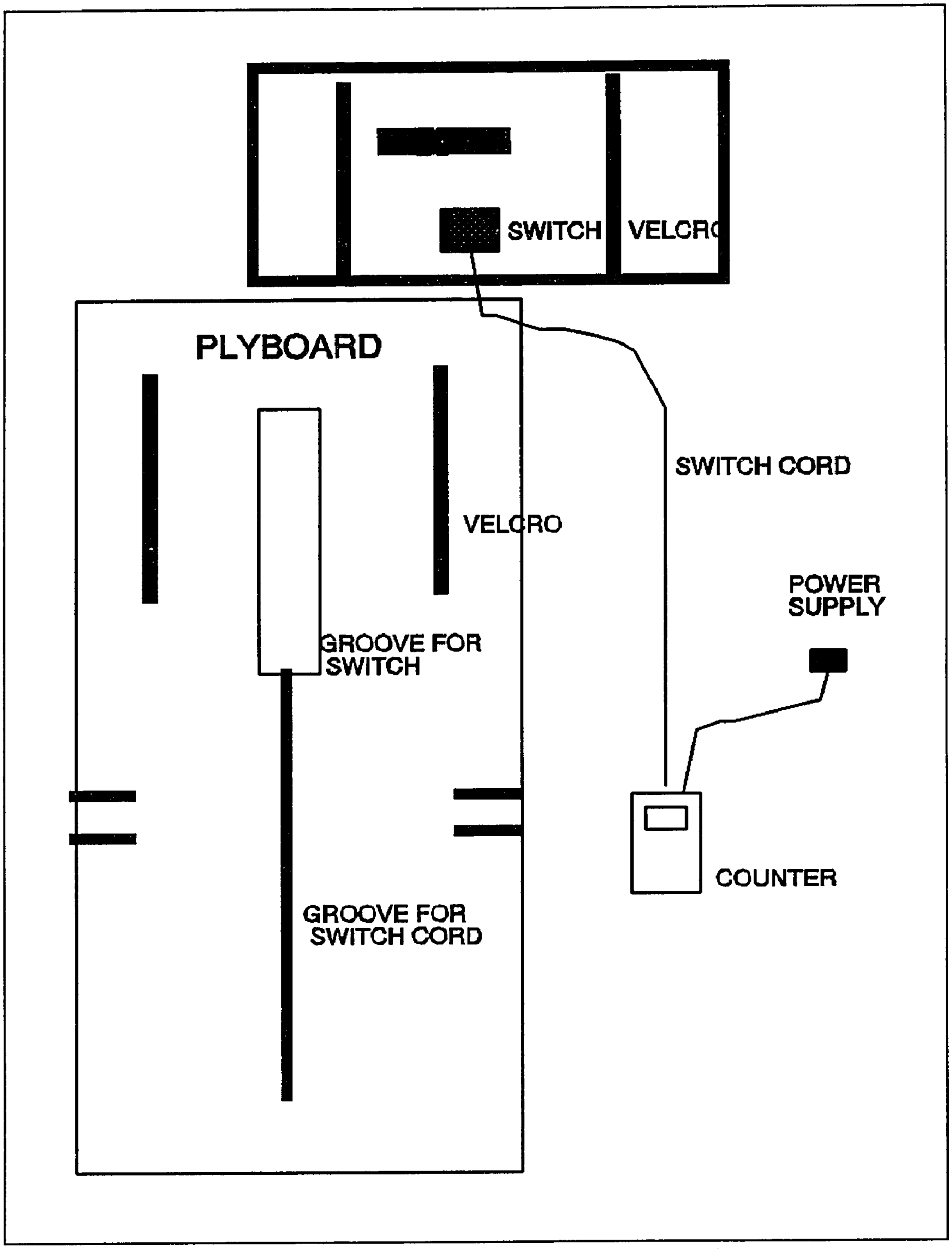


Illustration 1 - Schematic of Apparatus C / guide for construction

Appendix I

Raw data

EXPERIMENT 1 - TEST-RETEST RELIABILITY -RAW DATA

SUBJECT #	SEX	AGE	HEIGHT	WEIGHT	SITUPS	ABFOLD	HIPFOLD	TRIFOLD	THIFOLD	%FAT	STEP TEST	FITNESS	FLEXIBILI	SITUPS2	EXERCISE	FREQSUS
1	2	30	64	130	76	5	5	5	6	4.6	73	1	17	78	1	1
2	1	28	70	140	62	18	23	22	26	25.5	75	1	9	65	1	1
3	1	24	61	108	55	22	16	14	19	26.5	109	4	17	63	3	3
4	1	36	62	119	59	10	11	14	23	18.7	99	2	22	62	2	1
5	1	42	66	148	52	15	10	13	26	20	92	1	23	54	1	1
6	1	24	65	120	68	21	16	13	20	20.8	101	3	12	59	2	2
7	1	23	67	154	64	16	18	19	34	24.3	99	3	22	62	1	1
8	1	31	61	127	45	20	21	23	38	27.7	83	1	18	52	1	1
9	1	33	66	125	74	11	8	10	22	16.2	71	1	23	85	3	1
10	2	26	72	193	61	37	40	16	18	24	105	4	18	68	1	2
11	2	24	69	165	69	18	18	11	13	13.9	94	4	10	73	2	2
12	2	20	63	135	64	18	22	10	12	13.1	130	7	20	62	1	2
13	1	23	67	142	57	16	11	19	21	18.4	119	5	20	54	1	1
14	1	20	67	143	25	20	24	19	29	29.9	145	7	18	28	3	2
15	2	18	76	196	67	26	29	13	12	17.6	93	3	8	68	1	2
16	1	18	65	140	45	29	21	19	24	25.8	107	5	21	28	3	2
17	2	20	70	145	77	20	20	10	12	13.1	96	3	16	82	4	3
18	1	26	64	130	31	29	26	23	30	29.6	136	6	22	36	4	3
19	1	19	70	155	52	26	17	20	27	24.7	124	6	12	53	2	2
20	1	18	59	130	8	18	28	25	30	26.8	140	7	17	17	4	3
21	1	18	67	130	13	20	15	14	17	18.6	136	7	19	15	3	3
22	1	18	68	125	80	8	10	11	16	12.6	93	3	23	88	1	1
23	2	18	71	150	63	18	20	12	17	14.3	107	5	17	53	4	3
24	2	20	73	180	79	18	17	9	10	10.8	82	2	20	73	1	1
25	2	22	74	195	69	10	13	8	8	8.3	86	2	20	76	3	3

26	1	18	67	130	52	16	17	17	25	21.3	106	3	20	56	2	1
27	2	19	68	135	67	7	8	5	5	4.4	81	2	16	82	1	3
28	1	16	65	110	68	17	17	18	24	20.1	110	4	26	71	1	2
29	1	11	63	144	50	23	24	19	22	23.6	138	7	22	65	1	2
30	2	20	69	155	51	18	17	6	7	10.8	108	5	13	43	1	2
31	2	60	65	152	33	23	20	12	14	21.8	106	4	10	27	2	3
32	2	72	68	150	62	11	10	11	13	15.7	98	3	21	79	2	1
33	1	43	61	143	37	31	29	29	30	30.2	117	4	17	44	2	3
34	2	26	74	205	72	12	17	11	9	11.6	76	1	18	76	4	3
35	2	33	72	177	25	33	31	12		23.9	111	5	13	28	1	1
36	1	18	72	180	57	18	22	26	22	24.7	108	3	19	61	1	1
37	1	41	66	148	52	15	10	13	26	20	96	1	21	60	1	4
AV	1	26	67	147	55.2	19	18.4	15	19.6	19.3	104	4	17.8	58	2	2
SD	0	12	4	24.4	18	7	7.42	6	8.37	6.92	19.7	2	4.39	19	1	**

RAW DATA EXPERIMENT 2 - VALIDITY

SUBJECT #	SEX	AGE	HEIGHT	WEIGHT	1/2 SITUP	ABFOLD	ILIUMFOLD	TRIFOLD	THIFOLD	% FAT	STEPTEST	FITNESS	FLEXIBILITY	LHIP	RHIP	ABDOMEN	FULLSITUP	HIPTOTAL	EXERCISE	FRQSITUP	HIPAVERAGE
1	2	30	64	130	76	5	5	5	6	4.6	73	1	17	73	84	41	48	157	1	1	78.5
2	1	28	70	140	62	18	23	22	26	25.5	75	1	9	55	65	13	34	120	1	1	60
3	1	24	61	108	25	22	16	14	19	26.6	109	4	17	35	28	4.5	8	63	3	4	31.5
4	1	36	62	119	59	10	11	14	23	18.7	99	3	22	52	55	13.5	41	107	2	1	53.5
5	1	42	66	148	52	15	10	13	26	20	92	1	22.5	53	42	6	35	95	1	1	47.5
6	1	18	72	180	57	18	22	26	22	24.7	108	3	18.5	39.5	45	15	43	84.5	2	2	42.3
7	1	24	65	120	68	21	16	13	20	20.8	101	3	12	36	33	6.5	42	69	1	1	34.5
8	1	32	61	127	45	20	21	23	38	27.7	83	1	18	48	49.5	13.5	30	97.5	1	1	48.8
9	1	17	63	120	49	19	17	13	22	20.1	136	7	18	65	68	20	23	133	3	1	66.6
10	2	68	66	165	27	24	28	11	24	25	121	4	10	96	45	33	15	201	1	4	66.5

11	1	23	67	154	64	16	18	19	34	24.3	99	3	22	49	48	18	30	97	2	2	48.5
12	1	33	66	125	74	11	8	10	22	16.2	71	1	23	43.5	44	28.5	27	87.5	1	1	43.8
13	2	26	72	193	61	37	40	16	18	24.2	105	4	18	44	50.5	19	39	94.5	2	3	47.3
14	2	24	69	165	69	18	18	11	12	13.9	94	3	10	55.5	31	16.5	43	86.5	1	1	43.3
15	1	19	62	122	48	22	20	15	26	23.6	132	7	13	28	36	14	32	64	4	4	32
16	1	27	58	128	55	8	8	13	18	14.6	76	1	22	63.5	62.5	20.5	42	126	1	1	63
17	2	19	67	160	67	10	10	5	7	5.7	105	4	21	66.5	67.5	22.5	39	134	1	4	67
18	1	19	66	138	69	16	17	13	21	18.9	108	4	27	46	52.5	21.5	40	98.5	1	1	49.3
19	1	19	78	154	19	22	33	15	24	25.8	128	7	16	26	24	10	23	50	4	4	25
20	2	21	72	194	62	26	29	10	18	18.6	110	5	13	59	64	22	42	123	4	3	61.5
21	1	23	64	148	27	23	27	21	31	27.5	141	7	18	32.5	31	12	23	63.5	2	3	31.8
22	2	25	72	191	54	31	29	14	14	20.4	120	6	16	63.5	74.5	14.5	29	138	4	2	69
23	2	20	72	230	43	31	29	11	12	18.6	151	7	21	33	41.5	21.5	26	74.5	3	3	37.3
24	2	19	71	150	56	12	14	10	16	10.8	103	4	21	17.5	24.5	12	43	42	1	3	21
25	1	20	61	120	45	14	12	10	16	15.2	96	2	21	31	33	8	41	64	2	2	32
26	2	18	70	180	48	9	13	9	9	8.3	83	2	25	57	51.5	29.5	41	109	2	3	54.3
27	1	18	66	109	54	14	12	18	20	18.9	130	6	11	28.5	31.5	10.5	32	60	4	3	30
28	1	20	67	186	27	24	33	29	45	32.8	136	6	18	41	53.5	14.5	22	94.5	3	3	47.3
29	1	20	67	125	51	8	10	10	18	13.9	85	1	19	28	28.5	22.5	32	56.5	1	2	28.3
30	1	18	62	120	35	15	14	20	27	21.3	142	6	18	34	36.5	12.5	42	70.5	4	2	35.3
31	2	19	70	150	62	11	13	9	13	9.6	122	6	11	41	52	19.5	40	93	3	3	46.5
32	2	46	74	220	45	41	38	17	20	28.3	128	6	8.5	30.5	32	8.5	36	62.5	3	2	31.3
33	2	32	74	192	82	12	13	8	13	11.9	89	2	21	51.5	52.5	28.5	40	104	4	3	52

34	2	36	67	155	72	22	26	8	13	17.8	106	4	16	31	35.5	22.5	35	66.5	1	1	33.3
35	1	67	64	125	64	15	14	15	19	20.7	109	3	16	17	23	11	42	40	1	1	20
36	2	21	68	155	60	19	17	9	11	13.1	95	3	15	34.5	32	15.5	42	66.5	1	1	33.3
A	1	27	67	151	54	18	19	14	20	19.1	107	4	17.3	44.6	45.2	17.3	35	91.5	2	2	44.8
SD	**	12	4	31.4	15	8	9	6	8	6.69	21.3	2	4.67	16.7	15.4	8.01	9	34.4	1	1	14.9

RAW DATA EXPERIMENT 3 - INTERAPPARATUS RELIABILITY

SUBJECT#	SEX	AGE	HEIGHT	WEIGHT	HEADBUMP	ABFOLD	HIPFOLD	TRIFOLD	THIFOLD	% FAT	STEPTEST	FITNESS	AUTOSWCH	FLEX	REACH4"	ORDER	PREFER	EXERCISE	FRQSITUP
1	1	24	65	120	29	14	10	10	13	14.6	87	2	27	23	28	123	2	2	1
2	2	21	66	120	64	8	8	5	9	5.7	88	2	53	17	54	132	1	3	2
3	1	47	60	144	37	28	21	26	34	30.2	135	6	42	16	45	213	1	2	3
4	2	18	67	135	12	10	14	11	11	9.6	110	5	27	17	27	321	1	4	4
5	1	18	62	105	88	21	20	13	18	20.1	139	6	85	16	58	312	2	4	3
6	2	21	74	157	76	20	13	5	10	10.8	131	7	42	22	40	231	1	2	2

7	1	21	67	120	42	15	14	18	15	17.7	105	3	58	24	58	123	2	1	1
8	1	23	62	135	65	14	12	18	20	18.9	67	1	71	20	62	132	1	2	1
9	1	56	66	115	24	14	13	17	26	21.7	123	4	43	11	32	213	1	3	2
10	1	25	67	150	74	19	18	19	23	23.1	72	1	69	19	68	312	1	1	1
11	2	33	72	177	25	33	31	12	*	23.9	111	5	28	13	21	321	2	4	3
12	2	28	68	177	54	45	35	12	17	24.2	98	3	52	17	45	231	1	1	1
13	1	30	69	145	69	21	19	17	24	22.1	99	2	60	24	52	123	2	2	3
14	2	28	68	165	92	12	20	7	8	11.1	81	1	71	17	46	132	1	2	3
15	2	47	72	160	42	9	13	9	19	14.7	58	1	47	9	44	213	2	1	1
16	1	31	61	127	52	20	21	23	38	27.7	83	1	54	18	55	213	1	3	3
17	1	38	65	135	40	21	17	23	27	25.5	128	5	42	12	28	321	1	3	3
18	1	42	67	130	44	14	15	22	21	21.2	115	4	41	18	38	231	2	2	3
19	2	18	67	177	50	34	32	14	18	20.6	96	3	42	15	45	123	1	4	3
20	1	43	63	151	27	28	28	28	36	32.3	142	7	27	18	25	213	1	4	3
21	2	26	74	205	52	12	17	11	9	11.6	76	1	80	18	67	123	3	1	1
22	2	38	76	180	54	26	25	10	13	18.9	96	3	36	14	38	231	1	1	1
23	1	50	62	130	72	26	28	29	40	32.3	93	1	72	22	71	123	1	2	1
24	2	62	67	150	75	24	25	6	*	22.7	98	2	81	12	80	132	2	1	2
25	1	33	62	105	55	16	17	10	15	18.6	101	2	47	17	57	213	1	2	2
26	1	26	66	120	60	15	15	16	17	19.6	98	2	60	21	62	312	1	1	1
27	1	38	63	123	56	28	21	25	30	27.6	123	5	46	17	58	321	1	4	2

28	2	63	57	171	71	26	16	10	17	21.8	100	3	70	9	74	231	2	1	1
29	1	47	67	140	42	19	12	14	28	22.6	88	1	39	23	37	123	3	2	1
30	1	18	62	120	35	15	14	20	27	21.3	142	6	42	18	38	132	1	4	2
31	2	46	74	220	45	41	38	17	20	28.3	128	6	46	9	47	213	1	4	2
32	1	47	66	139	39	28	24	23	24	28.1	129	6	49	19	38	312	2	2	3
33	2	22	71	230	50	50	45	25	30	29.9	109	5	49	6	54	321	1	3	2
34	2	30	64	130	76	5	5	5	6	4.6	73	1	82	17	80	231	1	4	3
35	1	52	65	138	61	40	21	17	30	30.2	120	4	59	13	65	123	2	4	3
AV	1	35	66	147	53	22	20	16	20	21	104	3	53	17	50	211	1	2	2
SD	**	13	4	30.3	19	11	9	7	10	7.23	22.5	2	17	5	16	76.1	**	1	**

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