KINETIC, KINEMATIC, AND ELECTROMYOGRAPHICAL ANALYSIS OF INCLINE AND DECLINE PUSH-UPS WITH DIFFERENT CADENCES

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ABSTRACT

KINETIC, KINEMATIC, AND ELECTROMYOGRAPHICAL ANALYSIS OF INCLINE AND DECLINE PUSH-UPS WITH DIFFERENT CADENCES

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This study evaluated if the incline and decline push-up provided any advantage in weight training and physical therapy when compared to the standard push-up; the effects of different performance cadences were also investigated on the incline, standard, and decline push-up. Specifically, the purposes of this study were to examine, as a result of increased incline and decline angles and performance cadences: a) what are changes in the three maximum right hand forces, represented as a percentage of body weight? b) What are changes in the perpendicular hand force patterns when one switches from the incline push-up to decline push-up? c) Which muscle among the pectoralis major, triceps brachii, deltoid, and upper trapezius is the relatively most active one in a standard push-up, after muscle activities are normalized to the Maximum Voluntary Isometric Contraction (MVIC) test? and d) How do muscle recruitment patterns change from the incline to decline push-up? Twenty four college students and recreational weight trainers (age: 19.8±1.4 yrs; weight: 159.8±26.7 lbs; height: 173.9±9.5 cm) participated in this study. Each participant completed two preliminary phases and a formal testing phase on the same day. The formal testing phase consisted of 15 sets (5 body angles and 3 performance cadences) of push-ups, with 3 repetitions in each set.

Research question 1 (RQ 1): There exhibited a linear relationship between the increased incline angle (≅15 to 30 to 45 degrees) and the maximum anterior-posterior force (Fx) and perpendicular force (Fz) experienced at the right hand. The Pearson correlation coefficients for these two maximum forces were near -1 in the incline, standard, and decline push-up. There was no obvious relationship between the incline angle and the maximum medial-lateral force (Fy). **RQ 2:** The same results were generated for relationships between the increased decline angle (≅15 to 0 to -10 degrees) and the three maximum hand forces. **RQ 3:** It was unexpected that during a standard push-up with cadence 2 (30 beats/minute), the deltoid muscle, instead of the pectoralis major, was proven to be the relatively most active among the four muscles. **RQ 4**: When participants switched from the incline to decline push-up, the recruitment patterns of the deltoid and triceps brachii were found to be changed, but that of the pectoralis major and upper trapezius remained the same. **RQ 5:** In incline, standard, and decline push-ups, a higher performance cadence induced significant changes in the maximum hand forces. **RQ 6:** Fz patterns had a minor change from the incline to decline push-up. Only the phase during the eccentric period showed a presence of more maximum magnitude. **RQ 7:** In all three cadences, significant changes were found in the activation level of the four muscles between the incline, standard, and decline pushup. **RQ 8:** In all push-ups, a higher performance cadence induced statistically significant changes in the muscle activation level.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

This study focused on two variants of the standard push-up exercise: the incline push-up and decline push-up. CHAPTER one begins with the popularity of the push-up, proceeding to two main purposes for which the push-up is used and to the specific techniques of performance. This is followed by a table that contains the muscles involved during the standard push-up and the two variants. Finally the significance of and need for this study is stated, ending with a statement of the problem, research questions, hypotheses, limitations, assumptions, and definitions.

Introduction to the Push-up Exercise

Popularity of the push-up

Though considered simple and old-fashioned, the push-up remains one of the most popular exercises to strengthen the upper extremity muscles. No matter which branch of the U. S. military an individual joins, the push-up is part of the training routines. In some branches, like the Air Force, the score on the push-up evaluation can actually affect an individual's promotion. Not doing enough push-ups could lower the fitness score, and a failing score can result in withholding promotion (Bright, 2010). The push-up exercise is also one common denominator in weight training, such as weight training in boxing (Peterson, 2006). Some tests used in physical education programs, such as the Presidential Physical Fitness Test, use the push-up to assess upper body strength and endurance (McCahan & Cucina, 2003). It is evident that the push-up has become an essential part of many fitness and exercise prescription and programs.

Generally speaking, the popularity of the push-up comes from the benefits and convenience of the exercise: the lack of equipment requirements, the potential to perform it almost anywhere and anytime, the physical benefits that many age groups can acquire; in addition to the exercise's short learning curve and easy adaptability to various difficulty levels (Lou et al., 2001).

Two main purposes of performing the push-up

The standard push-up is mainly used for two purposes: a) assessment of strength and endurance of specific chest, shoulder, and upper extremity muscles; and b) exercise for strengthening of these muscles. As a tool for assessing muscle performance, the push-up is often incorporated in a battery of tests (e.g., the Army Physical Fitness Test, designed to evaluate individuals' fitness levels (Cogley et al., 2005)). As a form of exercise, its primary function is to develop strength and/or build up muscle volume.

Specific techniques of performing the push-up

Whether used as an assessment tool or a strengthening exercise, it is important to understand the proper way in which the movement is performed so that maximal benefits can be realized (Cogley et al., 2005). Among many resistance-training exercises, the push-up is a callisthenic exercise in which a portion of the body weight is used as the resistance. Although considered very simple and easy to learn, the push-up is not performed correctly by all people. According to the standards outlined in the Army Field Manual (FM 21-20), the standard push-up, or military push-up, should be performed from a front leaning rest position, with hands placed approximately shoulder-width apart on the ground, fingers pointing forward, feet up to 0.3 meters apart, and toes pressing into the floor. During the push-up exercise (see Figure 1.1), the performer should maintain a rigid and linear body position from the ankles to the shoulders via tight back, hip, abdominal, and leg muscles (LaChance & Hortobagyi, 1994). One detail is that many people lock their elbow joints at the end of the concentric phase, which compromises the maximal benefits of this exercise, since the muscles cannot reach the full working ability with a pause during the performance. The proper strategy is to extend the elbow joint to a point that is just short of lockout at the end of the concentric phase (Peterson, 2006).

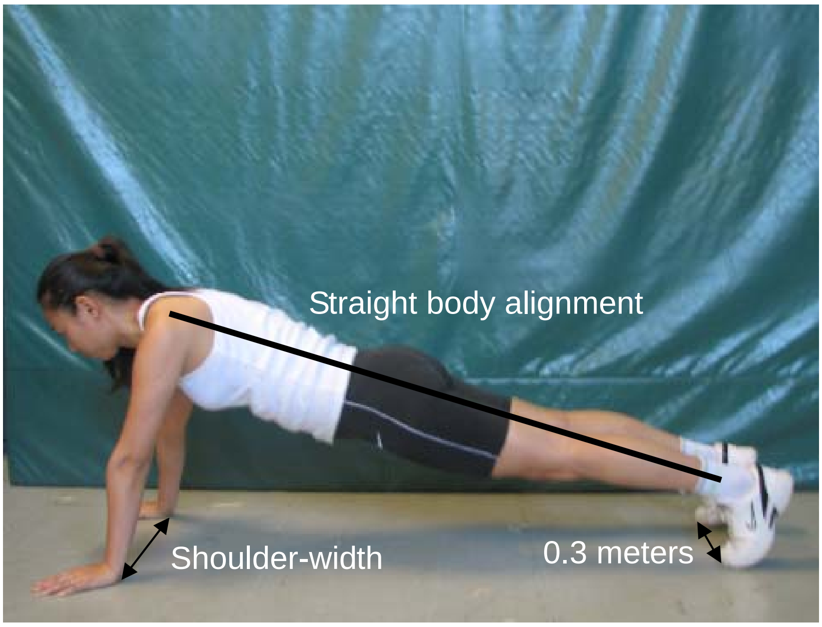

Figure 1.1 Example of body alignment of a standard push-up

(For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.)

One repetition of the push-up consists of two phases: eccentric and concentric. The repetition is started in a front leaning prone position. From this position, muscles of the upper extremities engage in eccentric contraction to lower the body toward the horizontal surface (ground) without permitting any relative alignment changes of the trunk and lower extremities. The repetition is completed by concentric contraction of muscles of the upper extremities without permitting any relative alignment changes of the trunk and lower extremities in returning to the starting front leaning position (see Figure 1.2). At the end of the concentric phase, the elbow joint should achieve near full extension without locking. Then, after a brief pause, another repetition may begin. A number of strength training coaches suggest a 2-second concentric and 4-second eccentric cadence; LaChance & Hortobagyi (2004) found that a higher cadence led to more repetitions and greater power output.

(a) (b) (c)

Figure 1.2 Example of a repetition of a standard push-up

(a) starting position, (b) maximum descent or end of eccentric phase,

(c) maximum ascent or end of concentric phase,

(a) to (b): eccentric phase, (b) to (c): concentric phase.

Muscles and movements involved in the standard, incline, and decline push-up

"No single movement simultaneously strengthens the chest, deltoid, lower back, and triceps quite as efficiently as the push-up," said Kurt Brungardt (1997), author of The Complete Book of Shoulders and Arms. During the push-up exercise, many upper extremity, trunk, and lower extremity muscles are activated to maintain the body alignment and complete the movement. Most of the trunk muscles and lower extremity muscles are used as stabilizers, while upper extremity muscles and some trunk muscles function as prime movers. During the eccentric phase, the motion of the shoulder joint is a combination of extension and horizontal extension, and the corresponding movement at the shoulder girdle is adduction, downward rotation, and reduction of lateral tilt, which is accompanied by the movement of elbow flexion.

During the concentric phase, the motion of the shoulder joint is typically a combination of flexion and horizontal flexion, and the corresponding movement at the shoulder girdle is abduction, upward rotation, and lateral tilt, which is accompanied by the movement of elbow extension. Table 1.1 contains information on the movements of the shoulder joint and corresponding movements of the shoulder girdle, accompanying movements of the elbow joint and active muscles during the eccentric and concentric phases of the push-up. In addition to the dynamic eccentric and concentric action at the shoulder joint, shoulder girdle, and elbow joint, muscles of the trunk and lower extremities contract isometrically to maintain a straight alignment of the trunk and lower extremities throughout each repetition of the push-up to provide a rigid lever which rotates about the interface of the feet and supporting surface. In short, during the push-up exercise, muscles from many parts of the body are activated; the stabilizers contract isometrically to keep the lower extremities and trunk rigidly aligned, and the prime movers are responsible for the dynamic motion.

Table 1.1

Muscles and Movements of the Shoulder Joint, Shoulder Girdle, and Elbow Joint during the Eccentric and Concentric Phases of the Standard Push-up

	Shoulder Joint		Shoulder Girdle		Elbow Joint	
	Move-ment	**Active Prime Movers**	**Move-ment**	**Active Prime Movers**	**Move-ment**	**Active Prime Movers**
Eccentric Phase	Exten-sion	Anterior deltoid, Pectorali-s major (clavicular potion)	Down-ward rotation, Adduc-tion,	Serratus anterior, Trapezius 2 and 4	Flexion	Triceps brachii
	Horizon-tal exten-sion	Middle deltoid, Posterior deltoid, Infraspin-atus, Teres minor	Adduc-tion, Reduc-tion of lateral tilt	Serratus anterior, Pectoralis minor, Trapezius 3, Rhomboid		
	Shoulder Joint		**Shoulder Girdle**		**Elbow Joint**	
	Move-ment	**Active Prime Movers**	**Move-ment**	**Active Prime Movers**	**Move-ment**	**Active Prime Movers**
Concentric Phase	Flexion	Anterior deltoid, Pectorali-s major (clavicular potion)	Upward rotation, Abduc-tion	Serratus anterior, Trapezius 2 and 4	Exten-sion	Triceps brachii
	Horizon-tal flexion	Middle deltoid, Posterior deltoid, Infraspin-atus, Teres minor	Abduc-tion, Reduc-tion of lateral tilt	Serratus anterior, Pectoralis minor, Trapezius 3, Rhomboid		

Variants of the standard push-up

Based upon the standard push-up, many variants were developed to meet the needs of different fitness programs, athletic levels, off-season and in-season sport training, and clinical conditions. These push-up variants include: incline, decline, sitting, wall, one-hand/arm, wide base (abducted), narrow base (adducted or close grip), dumbbell, medicine ball, modified (knee stance), drop and catch, finger, and more (see Definitions for descriptions of these push-up variants). Some researchers put push-ups into different categories according to their cadence (e.g., 4-second eccentric and 2-second concentric or 4-2 push-up, 2-2 push-up, and self paced push-up). These variants create great adaptability for the push-up exercise. While the popularity of push-ups results partially from their adaptability, a comprehensive analysis of their requirements regarding the applied forces and the muscular activity is important for the classification of the variants of the exercise into different difficulty levels (Gouvali & Boudolos, 2005).

Incline and decline push-up

The incline push-up is performed when the interface of the hands with supporting surface is elevated with respect to the interface of the feet with supporting surface. The incline push-up is different from the standard push-up due to the emphasis on elevated height of the hands and the resulted decreased difficulty level of performance. Modified from the standard push-up, the incline push-up should be performed from a front leaning rest position, with hands placed approximately shoulder-width apart on an elevated support, such as the edge of a bench, fingers pointing forward, feet up to 0.3 meters apart, and toes pressing into the floor (see Figure 1.3). During exercise, the performer should maintain a rigid body position from the ankles to the shoulders (LaChance & Hortobagyi, 1994). The incline angle is measured as the angle between a horizontal line and a line connecting the centers of the ankle and shoulder joints (see Figure 3.10); and as a result of the existence of the incline angle, the body weight is distributed more to the lower extremity in this situation than in the standard push-up. Therefore, the load bornee by the upper extremity, or, the difficulty level of the exercise, is decreased. The extent to which the difficulty level of the incline push-up is decreased depends on the magnitude of the incline angle.

(a) (b) (c)

Figure 1.3 Example of a repetition of an incline push-up

(a) starting position, (b) maximum descent or end of eccentric phase,

(c) maximum ascent or end of concentric phase.

The decline push-up is performed when the interface of the feet with supporting surface is elevated with respect to the interface of the hands and supporting surface, which is different from the standard push-up due to the emphasis on elevated height of the feet and the resulted increased difficulty level of performance. Modified from the standard push-up, the decline push-up should be performed from a front leaning rest position, with hands placed approximately shoulder-width apart on the ground, fingers pointing forward, feet up to 0.3 meters apart, and toes pressing into an elevated support, such as a bench or medicine ball (see Figure 1.4). During the exercise, the performer should maintain a rigid body position from the ankles to the shoulders via tight back, hip, abdominal, and leg muscles (LaChance & Hortobagyi, 1994). The decline angle is measured as the angle between a horizontal line and a line connecting the centers of the ankle and shoulder joints (see Figure 3.10) and as a result of the existence of the decline angle, the body weight is distributed more to the upper extremity in this situation than in the standard push-up situation. Therefore, the load bornee by the upper extremity, or, the difficulty level of the exercise, is increased. The extent to which the difficulty level of the decline push-up is increased depends on the magnitude of the decline angle.

(a) (b) (c)

Figure 1.4 Example of a repetition of a decline push-up

(a) starting position, (b) maximum descent or end of eccentric phase,

(c) maximum ascent or end of concentric phase.

Since the eccentric and concentric phase in the incline and decline push-up is very similar to that in the standard push-up, the muscles activated are likely to be the same ones. However, the loads placed on these muscles are likely to vary. According to the advice given by Dann Halem (2002), the incline push-up shifts the muscle emphasis to the lower pectoralis region, as well as the anterior deltoid and triceps muscles, while the decline push-up places the emphasis on the upper pectoralis region as well as the anterior deltoid and triceps muscles.

Which muscles will have greater relative involvement as measured by integrated electromyography (EMG) during these two variants is an important research question in this study. It is expected that the anterior deltoid and triceps will be more active during the incline and decline push-up than in the standard push-up. And it is likely that there is no difference in muscle activation level between the lower and upper pectoralis major.

Significance of the Problem

From a practical standpoint, the push-up exercise is one of the most important exercises to develop upper body strength, and using it properly is crucial to human performance and health. “Using it properly” means a high specificity in different variants, which is hard to achieve since many details in the push-up, such as the cadence, are not well studied.

Specificity is an important principle of resistance training. The principle of specificity dictates that conditioning exercise should be prescribed and performed only after careful identification of the purpose and goals of training. From a muscular fitness perspective, potential goals to be considered include the development of muscular strength, size, speed, endurance, and power output (LaChance & Hortobagyi, 1994). To better achieve the goals of effective training and rehabilitation, the incline and decline push-up should be carefully and thoroughly studied.

Since the incline and decline push-up has been rarely investigated, questions may arise when coaches are training athletes: What angles will best train the triceps brachii? What cadence will make the pectoralis major get the most muscle volume? How can injuries be avoided when an athlete is doing the decline push-up? The therapists may also ask “How can shoulder girdle injuries be healed by performing specific incline push-ups? And, “How can pain in the trapezius muscle be reduced without aggravating the teres minor?”

In addition, the prevalence of using push-ups in various fitness programs and clinical conditions requires more insight into detailed information of the incline and decline push-up. Only with the careful study of the two variants and a high specificity during the training, can good training effects be acquired.

Statement of the Problem

The overall purpose of this study of the push-up exercise is to examine the effects of two independent variables (a) body angle and (b) performance cadence on two dependent variables (a) maximum hand forces (anterior-posterior force (Fx), medial-lateral force (Fy), and perpendicular force (Fz)) at the right hand and (b) muscle activation level of four muscles (pectoralis major, triceps brachii, deltoid, and upper trapezius) in a complete cycle of push-up. This information will be able to be used to provide rationale for strength and conditioning programs and as a basis for exercise prescription. Specifically, the purposes of the study are to examine, as a result of increased incline and decline angles and performance cadences: a) What are changes in the maximum right hand forces; b) What are changes in the perpendicular hand force pattern; c) Which muscle among the pectoralis major, triceps brachii, deltoid, and upper trapezius is the most active one; and d) How muscle recruitment patterns of these muscles change from the incline to decline push-up.

Need for the Study

Though the push-up has been studied for a long time, as a weight training and assessment tool, there is a paucity of kinetic, kinematic, and electromyographic data regarding this activity because of difficulties in measurement (An et al., 1992). For the incline and decline push-up, detailed studies are even fewer.

Questions arise as the incline and decline push-up appears on the list of training and rehabilitation programs. Are these variants really more effective in some aspects than the standard push-up? How can they be properly performed? How can maximal benefits be achieved?

In athletics, examples of more specific questions that coaches want answers to are: Which target muscles can be more effectively trained by a certain cadence in a decline push-up? How can a shot put athlete perform better by incorporating an incline push-up into his/her training regimen?

In a rehabilitation center, the doctors and therapists might want to adopt a very special angle or cadence in the incline push-up to assist their patients to recover from some muscle injuries and avoid other muscle activation at the same time to prevent reinjury and/or reduce the stress on selected muscles.

In short, the unanswered questions and the concern for the proper and accurate use of the two variants in either the sports field or medical field indicate a need for this study.

Research Questions

The current study was conducted to answer the following eight research questions. In the attempt to answer these research questions the following conditions were established: two independent variables (body angle and performance cadence), were manipulated. For body angle five levels (-10, 0, 15, 30, and 45 degrees) were used. Push-ups with 30 and 45 degrees body angles were identified as incline push-ups; the push-up with 15 degree body angle was defined as the standard push-up, and push-ups with -10 and 0 degree body angles were defined as decline push-ups. Three levels of performance cadence were used: 20 beats/minute (or 10 push-ups per minute), 30 beats/minute (or 15 push-ups per minute), and 60 beats/minute (or 30 push-ups per minute). The cadence of 20 beats/minute was defined as cadence 1; the cadence of 30 beats/minute was defined as cadence 2; and the cadence of 60 beats/minute was defined as cadence 3.

RQ1. For the incline push-up, is there a relationship between the maximum hand forces, as a percentage of body weight, and incline angle? When the incline angle increases, will the maximum hand forces decrease?

RQ2. For the decline push-up, is there a relationship between the maximum hand forces, as a percentage of body weight, and decline angle? When the decline angle increases, will the maximum hand forces increase?

RQ3.Which muscle among pectoralis major, triceps brachii, deltoid, and upper trapezius is relatively most active in comparison to its recorded Maximum Voluntary Isometric Contraction (MVIC) during the typical standard push-up with cadence 2 (30 beats/minute)?

RQ4.Will the recruitment pattern of selected muscles (pectoralis major, triceps brachii, deltoid, and upper trapezius) be different in the incline and decline push-up at cadence 2 (30 beats/minute)?

RQ5.Will different performance cadences change the maximum hand forces (Fx, Fy, and Fz), as a percentage of body weight, that occur during the incline, standard, and decline push-ups?

RQ6.How does the pattern of the maximum perpendicular hand force (Fz) change from the incline push-up to decline push-up?

RQ7.How will electromyographic (EMG) activity of selected muscles differ among the incline, standard, and decline push-ups when normalized to Maximum Voluntary Isometric Contraction MVIC test?

RQ8.How will electromyographic (EMG) activity of selected muscles differ under the three different cadences when normalized to Maximum Voluntary Isometric

Contraction MVIC test?

Hypotheses

H1. During the incline push-up, as the incline angle increases, all three maximum hand forces (Fx, Fy, and Fz), as a percentage of body weight, will decrease. There is an inverse linear relationship between the increased incline angle and the three maximum hand forces.

H2. During the decline push-up, as the decline angle increases, all three maximum hand forces (Fx, Fy, and Fz), as a percentage of body weight, will increase. There is a direct linear relationship between the increased decline angle and the three maximum hand forces.

H3. The pectoralis major muscle or the deltoid will be the most active muscle during a standard push-up at cadence 2 (30 beats/minute).

H4. The recruitment pattern of some of the selected muscles will change from the incline push-up to decline push-up at cadence 2. The deltoid has the most possibility to change the pattern.

H5. It is hypothesized that in incline, standard, and decline push-ups, a higher performance cadence will induce a positive increase in the maximum hand forces, as a percent of body weight.

H6. It is hypothesized that for the incline and decline push-up, the pattern of the perpendicular force (Fz) will not change from the incline to decline push-up.

H7. It is hypothesized that the muscle activity of the four selected muscles will increase when the participant switches from the incline push-up to standard push-up and to decline push-up, or, switches directly from the incline push-up to decline push-up.

H8. It is hypothesized that the muscle activity of the four selected muscles will increase when the participant switches from the cadence 1 to 2 and to 3, or, switches directly from cadence 1 to 3.

Assumptions

- The participants have bilateral symmetry in the sagittal plane in their movements and patterns of application of muscular force throughout their performances of the variants of the push-up. That is, data collected from the right upper extremity will be the same as that which would be collected from the left upper extremity.

- The trunk and lower extremity will be held rigid and straight and rotate about the contact point between the toes and the supporting surface during the performances of the push-up variants.

- The participants will reach a maximum contraction during the Maximum Voluntary Isometric Contraction test (MVIC) test.

- Fatigue will not be a large threat to muscle activity during the testing.

- In the performance of the push-up, there are no gender and/or age differences in a) maximum hand forces (Fx, Fy, and Fz), as a percentage of body weight and b) muscle activation levels and patterns of selected muscles (pectoralis major, triceps brachii, deltoid, and upper trapezius).

Definitions

Abduction: The movement of a body part in a coronal plane away from the axis or midline of the body is called abduction. Or, it is the movement of a digit away from the axis of the limb (Van, 2002).

Activation Level: In this study, the activation level refers to the extent to which the muscle is activated, which is measured via electromyography (EMG).

Activation Pattern: The order in which muscles are activated is called the activation pattern. The activation pattern is a temporal sequencing that notes which muscles are active at any point in time and which ones are simultaneously active.

Adduction: The movement of a body part in a coronal plane toward the axis or midline of the body is called abduction. Or, it is the movement of a digit toward the axis of the limb (Van, 2002).

Angle Adjustment Box: A wooden box named angle adjustment box was built to facilitate changes in the incline and decline angle of the body for performances of variants of the push-up exercise (see *Figures 3.11, 3.12* and *3.13*). Two rows of holes on each side are used to support one to two steel bars, on which the performance board and wooden support can be supported. By switching between the two rows of holes, the angle of the performance board and height of the wooden support can be adjusted, so the incline and decline angle used for the push-up can be changed.

Anthropometer: The anthropometer is an instrument that is used to measure the absolute and relative variability in size of the human body (see Figure 3.7).

Burpee Push-up Test: The Burpee push-up test was designed by Japanese professor Sakamaki (1983), in which push-ups are used to measure endurance. The test is similar to the step test, and the endurance is estimated by measuring the heart rate within a three minutes time period in which participants keep doing push-ups at a pace set by a metronome.

Cadence 1: In this study, cadence 1 refers to a pace played by the metronome at 20 beats/minute.

Cadence 2: In this study, cadence 2 refers to a pace played by the metronome at 30 beats/minute.

Cadence 3: In this study, cadence 3 refers to a pace played by the metronome at 60 beats/minute.

Callisthenic: Callisthenic describes a form of organized exercise consisting of a variety of simple movements—performed without external weights or equipment—that are intended to increase body strength and flexibility using the weight of one's own body for resistance.

Center of the Ankle Joint: In this study, the lateral external center of the ankle joint which is defined by the lateral malleolus of the fibula bone is defined as the center of the ankle joint.

Center of the Shoulder Joint: In this study, the lateral external center of the shoulder joint which is defined by the greater tubercle of the humerus bone is defined as the center of the shoulder joint.

Closed Kinetic Chain Exercise: Closed kinetic chain exercise is a form of exercise in which the terminal joint is not free to move (Baechle & Earle, 2000). For example, in this study the push-up exercise is a closed kinetic chain exercise since no terminal joint associated with the hands and feet can move from their contact points during the performance.

Concentric Muscle Contraction: The phenomenon that a muscle is shortening during its contraction is referred to as concentric muscle contraction (Fleck & Kraemer, 2004). This type of contraction occurs when the force of the contraction of the muscle is greater than the force of resistance opposing the muscle contraction.

CRAFTSMAN Multifunction Digital Level: The CRAFTSMAN multifunction digital level (see *Figure 3.9*) is a digital professional angle measurement device with laser light. This versatile measuring tool is used for obtaining angles quickly and accurately, relative to the horizontal of the laboratory reference system.

Cuff Link Device: The cuff link is a closed kinetic chain rehabilitation apparatus for the upper extremity (Tucker et al., 2008).

Decline Angle: During the decline push-up , the decline angle is formed by a horizontal line and the straight line connecting the centers of the ankle and shoulder joints when the body is in a front leaning rest position prior to the start of the eccentric phase (see Figure 3.10).

Eccentric Muscle Contraction: The phenomenon that muscle is lengthening in a controlled manner during its contraction is referred to as eccentric muscle contraction (Fleck & Kraemer, 2004). This type of contraction occurs when the force of resistance opposing muscle contraction is greater than the force of the contraction.

Electrogniometer: In this study, the electrogoniometer is an instrument that is used during the performances of push-up variants to continuously measure the relative angle formed by the forearm and arm segments composing the elbow joint (see Figure 3.6).

Electromyography (EMG): It is a tool that is used to measure the electrical activity of muscles associated with their contraction.

Extension: Extension means moving apart of two ventral surfaces around a transverse axis (Gray, 1995). In this study, it means the moving away of adjacent body segments in a paramedian plane so that their two anterior/posterior surfaces are brought apart.

Externally Rotated Position: Rotation of a limb segment about its longitudinal axis such that the anterior surface comes to face away from the midline of the body is called externally rotated position. In this study, the forearm of participants will externally rotate 30 degrees when performing the push-up.

Finger Spread: The finger spread refers to the action of the spread of fingers.

Flexion: Flexion means approximation of two ventral surfaces around a transverse axis (Gray, 1995). In this study, it means the bending of adjacent body segments in a paramedian plane so that their two anterior/posterior surfaces are brought together.

Force Platform: Force platforms are measuring instruments that record forces and moments applied to them by a segment (e.g., foot, hand) of the human body in contact with the surface of the instrument. They are capable of measuring forces along three dimensional axes (Fx (anterior-posterior), Fy (medial-lateral), and Fz (perpendicular)) and moments about these axes.

Forearm: Anatomically the forearm is defined as the part of the upper extremity between the wrist and the elbow joint.

Front Leaning Rest Position: In this study, this refers to a position in which a practitioner’s body is leaning forward and stays still with two upper extremities straight and hands in contact with the floor or supporting surface (e.g., see Figures 1.1(a), 1.3(a), and 1.4(a)).

Hyperabduction: The hyperabduction is an extreme and abnormal abduction of a joint.

Hyperextension: The hyperextention is an extreme and abnormal extension of a joint.

Incline Angle: During the incline push-up, the incline angle is formed by a horizontal line and the straight line connecting the centers of the ankle and shoulder joints when the body is in a front leaning rest position prior to the start of the eccentric phase (see Figure 3.10).

Intensity: Intensity represents the level of muscle activity that can be quantified in terms of power. Alternatively, it is the efforts expended during training (Baechle & Earle, 2000).

Internally Rotated Position: Rotation of a limb segment about its longitudinal axis such that the anterior surface comes to face towards the midline of the body is called internally rotated position.

Isokinetic Dynamometers: An isokinetic dynamometer is a device for measuring the torque, force, or power applied to a shaft that rotates with a constant angular velocity that can be set at various magnitudes.

Jumping Jacks: Jumping Jacks are a type of physical exercise performed in an upright standing posture by jumping to a position with the legs spread wide and in contact with the ground, and the hands touching overhead and then returning to the standing position with the feet together and the upper extremities at the sides of the body.

Kinetic: Kinetic describes the forces that cause motion.

Kinematic: Kinematic refers to parameters that describe motion (e.g., position, velocity, and acceleration) without concern for the forces that cause the motion.

LabVIEW System: LabVIEW is an abbreviation for Laboratory Virtual Instrumentation Engineering Workbench. The system is a software and hardware package that is used mostly in the engineering field for data acquisition, instrument control, and industrial automation.

Lockout: This is a position achieved by the segments of a joint at which point they have reached their maximum relative range and the bones forming the joint are “locked” in position. This occurs in the elbow joint when the joint has reached maximum extension.

Metronome: A metronome is a device used to mark time by means of regularly recurring sound ticks or electronic flashes at adjustable intervals.

Muscle Activation: The recruitment of motor units of muscles during contraction in response to different loading conditions is called muscle activation. A force is usually generated during muscle activation.

Muscle Strength: During muscle contraction, the physical force that is generated is muscle strength.

Muscle Volume: The size of a muscle or a muscle group is the volume of the muscle or muscle group.

Narrow Base: When a push-up is performed with the distance between hands less than 100% of shoulder-width, it is called the narrow base push-up, or adducted push-up.

Neutral Position: When performing a push-up in the neutral position, a practitioner's hands are pointing forward without pronation or supination of the proximal and distal radioulnar joints or inward or outward rotation of the shoulder joints.

Performance Board: A wooden board was built with a force platform attached on the right surface and a wooden blank on the left surface. There are two hooks on the head of the performance board so it can be hung on the angle adjustment box to change the incline and decline angle for performances of the push-up (see Figure 3.13).

Plank Position: In this study, when the push-up is performed with a straight alignment of trunk and lower extremities, the position of "keeping straight" is called the plank position.

Press Up: Press up is anther name of the push-up in British English. In this study, "push-up" is used instead of "press up".

Prime Mover: The prime mover is a muscle that acts directly to produce a desired movement amid other muscles acting simultaneously to produce the same movement indirectly.

Range of Motion: The range of motion is also named the degree of motion. It is the functional or maximum angular range achieved between the flexed position and the extended position of a particular joint.

Regular Base: When a push-up is performed with the distance between hands equal to 100% of shoulder-with, it is called the regular base push-up. For example, the standard push-up has a regular base.

Repetition (Rep): It is a single complete movement of an exercise (Fleck & Kraemer, 2004). For example, in this study, one complete repetition of the push-up includes a complete eccentric and concentric phase.

Shoulder-width: Linear distance from the lateral edge of the left shoulder to the lateral edge of the right shoulder is called shoulder-width.

Shoulder Protraction: The shoulder protraction is also called scapular protraction. It is the motion of starting in the push-up position and rolling shoulders forward (Lehman et al., 2008).

Stabilizer: A stabilizer is a muscle that acts to provide support and stability for the prime mover, so together they can produce a desired movement.

Step Test: The step test is widely accepted as a simple method of measuring cardiovascular endurance. The procedure is to step on and off a 12-inch high box for three minutes. At the end of three minutes, one remains standing while the heart rate is immediately checked.

Upper Extremity: Upper jointed appendages of humans are called upper extremities. An upper extremity is composed of an arm, forearm, and hand. The upper extremity is also called the upper limb.

Wide Base: When a push-up is performed with the distance between hands greater than 100% of shoulder-with, it is called the wide base push-up.

Push-up Variants

Back Hand Push-up: A variant from the standard push-up in which the practitioner contacts the floor with the toes and backs of hands, instead of the palms.

Boxer's Push-up: When performing the boxer's push-up, the practitioner usually wears boxing gloves. Instead of placing the palms on the ground, the practitioner places the knuckles of his/her boxing gloves against the floor without bending the wrist joints.

Clapping Push-up: The clapping push-up is an old push-up variant used in China and India. It is very similar to plyometric push-up in which the hands no longer support the body at the end of a forceful concentric phase. During this non-support of the upper body, the practitioner adds the movement of clapping his/her hands prior to the hands regaining contact with the supporting surface to begin the eccentric phase.

Decline Push-up: The decline push-up is a variant of the standard push-up. It is performed when the interface of the feet and supporting surface is vertically elevated with respect to the interface of the hands and supporting surface (see Figure 1.4).

Drop and Catch Push-up: In the drop and catch push-up, the practitioner places two boards under the hands for elevation. He/she pushes the body into air with explosive force and concentric contraction; when the body is dropping, the practitioner will land on the floor to catch the body (prevent the body touching the floor) during the eccentric phase; then, the practitioner moves hands back to the boards and begin another repetition.

Figure 1.5 Example of a drop and catch push-up

Dumb Bell Push-up: The dumb bell push-up is a variant of the standard push-up. It is performed in a similar manner to the standard push-up except the body is supported with the hands each holding a dumb bell.

Figure 1.6 Example of a dumb bell push-up

Elbow Push-up Plus: The elbow push-up plus is a variant of the standard push-up plus. It is performed in the same way as the standard push-up plus except that the elbows are the proximal point of contact with the ground rather than the hands (Ludewig et al., 2008).

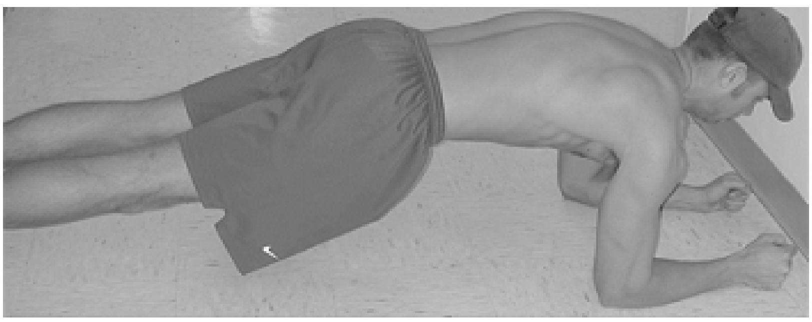

Figure 1.7 Example of an elbow push-up plus

Finger Push-up: The finger push-up is a variant of the standard push-up in which the practitioner's hands contacts the floor with only the fingers. The palms of the hands do not make contact with the supporting surface.

Fist Push-up: The fist push-up is a variant of the standard push-up in which the practitioner's fists contact the supporting surface. It is similar to the boxer's push-up, except the practitioner does not wear boxing gloves.

Hand Stand Push-up: The hand stand push-up requires the most strength among all the push-up variants. To do the hand stand push-up, the practitioner supports all the body weight in a hand stand with only two hands, with body straight and feet free of support or lightly pressed against a wall. From this position, the practitioner lowers and raises the body to complete the eccentric and concentric phase.

Hindu Push-up: The Hindu push-up is also named Indian push-up. The practitioner assuming a Hindu push-up position should keep his/her hands shoulder-width apart. At the end of the concentric phase, the practitioner lowers his/her trunk more than in a standard push-up to make the anterior surfaces of the thigh touch the mat without the abdomen touching the mat.

Figure 1.8 Example of a Hindu push-up

Incline Push-up: The incline push-up is a variant relative to the standard push-up. It is performed when the interface of the hands and supporting surface is vertically elevated with respect to the interface of the feet and supporting surface (see Figure 1.3).

Knee Push-up Plus: The knee push-up plus is a variant of the standard push-up plus. It is performed in the same way as the standard push-up plus except that the knees are the distal point of contact with the ground rather than the toes (Ludewig et al., 2008).

Figure 1.9 Example of a knee push-up plus

Loaded Push-up: In the loaded push-up, an extra weight is placed on the back of the participant who is to engage in the movement of a standard push-up. The weight is added to increase the difficulty of the exercise.

Maltese Push-up: The Maltese push-up is a gymnastic exercise, as well as wide base form of the push-up, in which the practitioner's hands are positioned closer to the hips than to the chest and with a great distance of over 150% of shoulder-width between them.

Figure 1.10 Example of a Maltese push-up

Medcine Ball Push-up: In the medicine ball push-up, the participant places the hands on a medicine ball instead of the floor. This is a type of incline push-up.

Military Push-up: Military push-up is anther name of the standard push-up.

Modified Push-up (Knee-stance Push-up): The modified push-up is also named knee push-up. It is a variant of the standard push-up in which the knee joints are flexed and in contact with the floor.

Figure 1.11 Example of a modified push-up

Narrow Base Push-up (Adducted or Close Grip Push-up): Based upon the standard push-up, the narrow base push-up is a variant in which the distance between the two hands is less than shoulder-width.

One-hand/arm Push-up: The one-hand/arm push-up is a variant of the standard push-up in which the participant contacts the floor with toes and just one hand instead of two hands.

Plache Push-up: The plache push-up is an extremely difficult push-up in which the practitioner performs only with hands, without placing the feet on the floor. This variant requires great strength and a high level of balance, since the body's center of gravity must be kept over the hands while performing and the legs are elevated in the air.

Figure 1.12 Example of a plache push-up

Plyometric Pus-up: The plyometric push-up is performed by first assuming the standard push-up position. The practitioner inhales and slowly lowers the trunk down to the floor, holding this position for about one second. Then, with explosive force, the practitioner exhales and pushes off forcefully enough so that the hands leave the ground and the trunk stays in the air for a short moment before landing back on the hands.

Seated Push-up (Sitting Push-up): The seated push-up is also called the chair push-up. It is a push-up variant in which the body is lifted by the upper extremities pushing against the arms of a chair. This type of push-up variant is often used by individuals using wheelchairs.

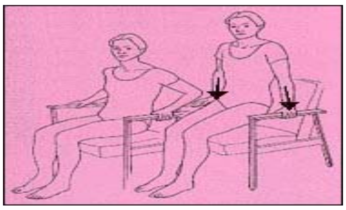

Figure 1.13 Example of a seated push-up

Standard Push-up: The standard push-up is an upper-body strengthening exercise. To correctly perform the standard push-up, one lies facedown with hands flat on the floor parallel to chest, head up slightly. Hand position should be just outside and slightly in front of shoulders. The trunk and lower extremities should be aligned straight. Body should be lifted by straightening the elbows and engaging the shoulder joints in flexion and horizontal flexion to achieve a front leaning rest position with only the hands and toes are in contact with the supporting surface (see Figure 1.2).

Standard Push-up Plus: The standard push-up plus is a variant of the standard push-up with the addition of full shoulder protraction (the “plus”) after obtaining full elbow extension (Ludewig et al., 2008).

Figure 1.14 Example of a standard push-up plus

Suspended Push-up: The suspended push-up is a variant of the standard push-up in which the participant’s hands are in contact with two rings suspended from the ceiling instead of the floor.

Figure 1.15 Example of a suspended push-up

Unsymmetrical Push-up: The right unsymmetrical push-up is a variant of the standard push-up in which the participant places the right hand on the floor about six to eight inches in front of and slightly to the right of right shoulder, and aligns the tips of left fingers under left shoulder. For the left unsymmetrical push-up, the left hand is placed in front of and slightly to the left of the left shoulder and the tips of the right fingers are placed under the right shoulder.

Figure 1.16 Example of an unsymmetrical push-up

Wall Push-up: The wall push-up is a variant of the standard push-up in which the practitioner is in a standing position with the hands in contact with a wall and feet away from the wall to create a body lean towards the wall.

Wall Push-up Plus: The wall push-up plus is a variant of the standard push-up plus in which the practitioner's hands are in contact with a wall in a standing position (Ludewig et al., 2008).

Wide Base Push-up (Abducted Push-up): Based upon the standard push-up, the wide base push-up is a variant in which the distance between the two hands is greater than shoulder-width.

CHAPTER 2: LITERATURE REVIEW

For this study, references from 1969 to 2010 investigating the push-up exercise were collected. These references indicated that the push-up motion is a topic of extended interests.

CHAPTER 2 was written in three sections. The first section of this chapter provides an overview of the push-up exercise. Backgrounds, some questions, and formally defined techniques for the incline and decline push-up are addressed to form a basis for what should be expected in this study.

The second section of this chapter containes analysis of techniques, including a review of several dependent variables associated with the mechanics of the performance of the push-up: ground reaction forces experienced at the hands as a percentage of body weight, elbow joint angle, and electromyography (EMG) from contributing muscles. Methods of analysis, including kinetics, kinematics, and EMG, are described.

The last section included a discussion of other facts about the push-up recorded in the literature, such as gender differences.

Overview of the Push-up

The push-up exercise has a long and interesting history. Thousands of years ago in China, the push-up was used for basic strength training for ancient swordsmen. The Chinese martial art name for the push-up translated into “declining tiger”. Many variants, such as finger and fist push-ups, were used in that period of time to increase the difficulty of this exercise to achieve more strength in specific muscles groups. In western worlds, “its original crude form was invented by ascetics in the 10th century as a form of self-flagellation. During the 20th century, it was refined by the Nazis into a highly efficient means of torture (Lhooqtius Ov, 2009).” After World War II, the US military began to adopt the push-up as an exercise in the training of its recruits. In American English, the term “push-up” has been commonly used since 1905, while in the British English, the prevalent term is “press-up”, which was first recorded in 1945.

As stated in CHAPTER 1, from the perspective of training and rehabilitation purposes, the push-up exercise is mainly used as part of strength training programs and an exercise assessment tool. However, from the perspective of non-training purposes, this exercise is adopted as a mild physical punishment in the military, a method of showing off one’s fitness, and even a form of entertainment competition. According to Wiki (http://www.wikipedia.org/), Guinness World Records, Paddy Doyle of the UK set a record of 1940 in one hour for a maximum number of two handed push-ups (push up with back hands) in 2007. The record for the most non-stop was 10,507, which was set by Minoru Yoshida from Japan in October, 1980 (Wiki, 2009).

Generally speaking, the physical benefits of the push-up exercise include: a) developing more muscle fiber volume to build up the whole body, especially upper body strength; b) improving bone density; c) increasing stability and flexibility of joints;

d) strengthening ligaments; e) accelerating blood flow; and f) boosting nerve and lung functions (Invergo et al., 1991; Halem, 2002; Howarth et al., 2008).

Considering the push-up is one of the most used exercises for strength training of the upper extremities, many variants and methods were developed to increase the possibilities of customization. In addition to the most common variants introduced in CHAPTER 1, there are more difficult push-up variants, including planche push-up, boxer's push-up, Maltese push-up, Hindu push-up, hand stand push-up, loaded push-up, unsymmetrical push-up (Lee, 2008), plyometric push-up, and clapping push-up.

In addition to these methods and variants, new devices have also been introduced in recent years to be combined with the performance of the push-up. These devices range from simple platforms and benches, to dumbbells, medicine balls, and specially designed hand grips (Anderson et al., 1984).

Like many forms of physical training and conditioning, the push-up exercise is associated with long believed traditions about the proper methods and techniques that are necessary to cause improvement. In addition, new training methods, variants, and devices are often introduced touting to produce superior physical development. Among these techniques, many of them concentrate on emphasizing specific muscles or generating greater muscle activities. Although some of these methods, variants, and devices have been tested scientifically, many have not and do not have evidence for justification of their use (Ebben & Jensen, 2002; McBride, Cormie, & Deane, 2007; Bruenger, 2008). For example, relative to the standard push-up, Halem

(2002) and Peterson (2006) indicated that the emphasis shifts slightly to the lower pectoralis major as well as the anterior deltoid and triceps brachii during the incline push-up. However, there is no evidence to prove this statement. Thus, proposed results from the use of incline and decline push-ups are non-validated training outcomes.

Despite the popularity of the push-up exercise, there have been very few studies concentrating on the incline and decline push-up. Even the specific techniques of performing the incline and decline push-up remained unclear. According to some anecdotal descriptions of the incline and decline push-up, the specific techniques of performing these two variants are as follows:

The incline push-up is performed on a flat bench or chair positioned in front of the practitioner whose feet are on the ground, torso in a plank position, and hands shoulder-width apart gripping the edge of the support. The head should be neutrally aligned so the spine is straight. From this position, the practitioner lowers his/her torso until the shoulder joint is 90 degrees and presses back up to the start position (Halem, 2002; Minkwitz, 2006).

The decline push-up is performed by placing the feet on a bench or other elevated supporting surface and hands on the ground. The trunk should also be straight and the head neutrally aligned. From this starting position, the practitioner lowers his/her torso and presses back up to the start position.

Although the performance of the incline and decline push-up seems very simple, many details of these variants were still not clearly elucidated in the research literature (LaChance & Hortobagyi, 1994). Should a wide base or a narrow base be used when performing these two variants? If a hand position of 100% of shoulder-width is adopted, to which locations on the hands should this distance be determined? Should the hands be placed in a neutral position or an internally or externally rotated position? And, a rotation of how many degrees is appropriate (Lou et al., 2001; Chou, et al., 2002)? Why should a 90 degree flexion at the elbow joint be achieved during the eccentric phase? Should the feet be apart or together? Does the performance cadence have an influence on the elbow joint angle during the push-up?

Because traditions and practices associated with the performances of variants of the push-up tended to lack validated outcomes, the current study was conducted to determine relationships between the existence of variables in body orientation and cadence and biomechanical performance parameters. To improve the validity of the study, the undefined techniques of performing the incline and decline push-up were defined in the following paragraph.

Individuals performing the incline and decline push-up started in a standard push-up position, with an elevation at the hands or feet. The body angle was adjusted using the control board and box (see Figure 3.12). The regular base of 100% of shoulder-width was used, and the distance was measured from the medial edge of the right thumb to that of the left thumb. The hands were placed in a slightly externally rotated position, with a 30 degree angle at the middle finger (see Figures 2.1 and 3.14). Three performance cadences of 20, 30, and 60 beats/minute were complied with by each participant. The completion of each eccentric and concentric phase of the push-up occurred on a beat (i.e., 2 beats per repetition).

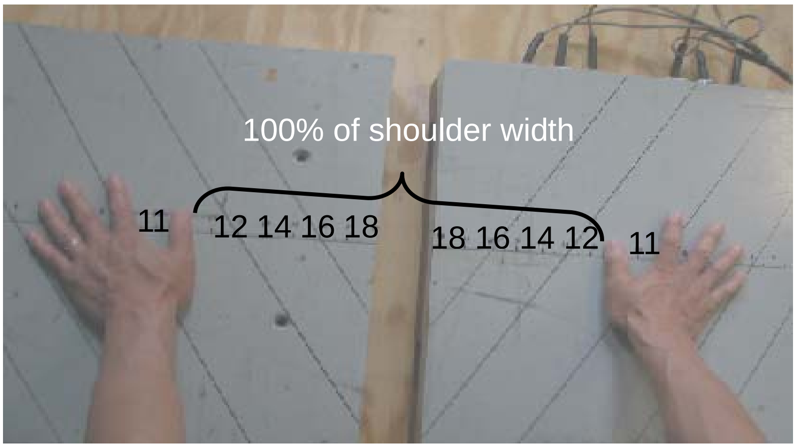

Figure 2.1 Hand orientation for the incline and decline push-up

The most discussed topic about the incline and decline push-up was muscle activation. Due to the different body weight distribution caused by different body angles, many coaches believed that the lower portion of the pectoralis major muscle was more active during the incline push-up; while upper pectoralis major was more active during the decline push-up. From the anatomical perspective, this theory seems reasonable. However, no electromyographic evidence to prove it was found in the literature.

Analysis of Techniques

In studies of the push-up exercise, the most commonly selected independent variable was the position. The effects of different body and hand positions, especially hand positions, were most often compared. Additionally, the push-up cadence was a prominent independent variable to be studied. The dependent variables included forces and moments applied on the palm, elbow joint load, elbow joint angle, and EMG data from selected muscles. Force platforms, electrogoniometers, and Electromyography (EMG), were the most used instruments for collecting data.

Kinetic and kinematic analysis

Interests in the actual patterns of movement of humans and animals goes back to prehistoric times and was depicted in cave drawings, statues, and paintings. However, it was not until a century ago that the first motion picture cameras recorded locomotion patterns of both humans and animals. A French physiologist, Etienne-Jules Marey, used a photographic “gun” in 1885 to record displacements in human gait and chronophotographic equipment to generate a stick figure diagram of a runner. At about the same time, Eadweard Muybridge sequentially triggered 24 cameras to record the patterns of a running man (Winter, 1990). Analysis of human movement has progressed rapidly from these studies. Now the term used for the descriptions of human movement is kinematics. Kinematics is not concerned with the forces that cause the movement, but rather with the details of the movement itself, such as linear and angular displacements and velocities.

More recent advances in the study of human movement have occurred through development of instrumentation to study the forces and the resultant energetics. This area of study is called kinetics (Winter, 1990).

The use of kinematics and kinetics evaluation has led to a deeper understanding of the push-up exercise. Table 2.1 provided a summary of eight studies that had conducted kinematics and kinetics analysis of the push-up. The methods of data collection reported included force platforms, cameras, electromagnetic sensors, and certain motion analysis systems (An et al., 1990, 1992; Donkers et al., 1993; Ikawa & Tokuhiro, 1995; Lou et al., 2001; Chou et al., 2002; Kotani & Tokuhiro, 2002; Howarth et al., 2008). As technology has progressed, more advanced motion analysis systems and infrared cameras have been utilized. The progress made as a result of these advanced instruments includes an easier recording process, more accurate data acquisition, and real-time monitoring of an experiment.

To thoroughly understand the use of the push-up as a strengthening and rehabilitating exercise and as a physical assessment tool, kinematics and kinetics analysis is necessary. There is a paucity of kinematics and kinetics data on this activity because of difficulties in measurement (An et al., 1990).

Among the eight kinematic and kinetic studies of the push-up (reported in Table 2.1), the hand force and intersegmental joint load attracted a lot of interest. Intersegmental joint load was defined as the force and moment generated at a joint as a result of externally applied and inertial load. This intersegmental load was eventually balanced internally by muscle forces and joint constraining forces from the capsuloligamentous and articulating structures. For a given joint, the intersegmental joint load can be calculated on the basis of the kinematics and kinetics data of the segments either distal or proximal to the joint. For the push-up exercise, it was considered easier to calculate the intersegmental joint forces and moments based on the distal segment forces and moments (An et al., 1990).

An et al. (1990) was an expert in conducting kinematics and kinetics study of the push-up. She constructed a very useful model to calculate forces and moments experienced at the wrist, elbow, and shoulder joints using a 3Space Tracker System and force plate. In her experiment, a 4-segment model was developed, with coordinates of each joint obtained by a transformation matrix with respect to a source coordinate system (the global laboratory system). Finally, forces and moments at the wrist, elbow, and shoulder joints were calculated via inverse dynamics based on the coordinates and the forces and moments exerted on the hand. On the basis of this model, An et al. (1990) conducted further research on the elbow joint load for six variants of the push-up. She found that the pattern for “normal” (standard) push-up forces exerted on the elbow joint along the forearm axis was similar between participants, with a force of approximately 36.8% of body weight at the static “up’ position and a maximum value of 45.2% of body weight at the “down” position where the participant began to ascend. The important findings include the effects of hand positions, which significantly affect the axial force on the elbow joint. To be precise, the wide base hand position elicited a decrease in maximum Fx (anterior-posterior force) from 45.2% to 42.7% of body weight as compared to the regular base (shoulder-width) position, and a wide base hand position also decreased the peak force at the elbow joint significantly. The peak torque at the elbow joint in the regular base position was 56% of a maximal isometric extensor torque, while the wide base and narrow base position generated torques of 29% and 71% of the maximal isometric torque, respectively (An et al., 1990, 1992; Donkers et al., 1993). Therefore, the values of the forces and moments at the elbow joint indicated that the results in these studies were consistent with that from the EMG research, thus supporting the wide base hand position as the easiest to perform among all the bases.

The effects of hand positions on the balance of paraplegic and tetraplegic patients were also investigated. To find an effective way to handle wheelchairs, three-dimensional floor reactions of the hand and angular deviation of the elbow and wrist joints during the sitting push-up exercise with four hand positions were studied. Results demonstrated that the anterior-posterior force (Fx) and medial-lateral force (Fy) are good indicators of body balance. The stability of the body during the sitting push-up resulted in an earlier and longer Fx and Fy force (Ikawa & Tokuhiro, 1995). Kotani and Tokuhiro (2002) studied the pressure exerted by the hands in the performances of the push-up exercise in 21 paraplegic and two tetraplegic patients employing four different hand positions. In the fingers spread position, the initial force exerted was a vertical force (Fz), followed by a medial-lateral force (Fy) and then an anterior-posterior force (Fx). In the other three positions (fist, palm, and push-up device), the order of force exertion was Fz, Fx, and then Fy. The fact that Fy was initiated before Fx in the fingers spread position indicated that lateral balancing of the trunk was critical in this position.

Elbow joint loading was also evaluated for the push-up exercise at three forearm rotations: up (neutral position of the hand), middle (the hand is internally rotated 90 degrees), and down (the hand is externally rotated 90 degrees). It was noted that greater posterior and varus forces of the elbow joint were encountered with internal rotation of the hand. The investigators suggested that the push-up with hands in an internally rotated position should be prevented so as to avoid excessive shear forces or moments (Lou et al., 2001). Likewise, Chou et al. (2002) studied these three forearm rotations for the one-hand push-up. He found the peak axial forces exerted on the elbow joint was approximately 65% of the body weight when the hand position was neutral, and was significantly reduced when the hand rotated either internally or externally. However, the peak valgus shear force with the hand externally rotated was 50% greater than the other two positions. The conclusion was that outward rotation of the hand was a stressful position that should be avoided during the one-hand push-up exercise or forward falls with outstretched hands in order to reduce the risk of elbow injuries. Chou et al.'s results (2002) were consistent with that of Donkers et al. (1993), in which the valgus torque increased by 42% for the one-hand push-up under simulated fall conditions.

Table 2.1

Summary of Kinetic and Kinematic Evaluations of the Push-up Exercise

Author (Date)	**Participants**	**Model**	**Kinematic & Kinetic Method**	**Method of Evaluation**
An et al. (1990)	1 male	4 segment (hand, forearm, arm, & shoulder)	3Space Tracker System & force plate	3-D inverse dynamics
An et al. (1992)	9 males	4 segment (hand, forearm arm, & shoulder)	3Space Tracker System & force plate	3-D inverse dynamics
Donkers et al. (1993)	9 males	4 segment (hand, forearm arm, & shoulder)	3Space Tracker System & force plate	3-D inverse dynamics
Ikawa & Tokuhiro (1995)	10 males	2 segment (wrist & elbow)	Force plate & goniometer dynamics	3-D inverse
Lou et al. (2001)	10 males	3 segment (hand, forearm & arm)	Six cameras, force plate, & video	3-D inverse dynamics
Chou et al. (2002)	8 males	3 segment (hand, forearm & arm)	Six cameras, force plate, & video	3-D inverse dynamics
Kotani & Tokuhiro (2002)	23 males & females	2 segment (wrist & elbow)	Force plate & goniometer dynamics	3-D inverse
Howarth et al. (2008)	11 males	Not specified	Sensors & triaxial force transducers	3-D inverse dynamics

EMG evaluation

The most important tool for evaluating muscle activities during the push-up exercise is electromyography (EMG). EMG measures muscle activity by detecting the electrical signals from muscles. A motor neuron and all the muscle fibers it innervates are known as a motor unit. Many motor units comprise each muscle. For a muscle to contract, one or more of its motor units must receive a signal from their corresponding motor neurons. The number of muscle fibers in a motor unit innervated by a motor neuron is dependent on the function of the muscle. Muscles typically involved in forceful and gross movement are composed of motor units in which there are relatively more muscle fibers per motor unit. On the other hand, muscles typically composed of motor units whose function is fine motor control have a ratio of relatively few muscle fibers per motor unit. When a muscle is contracting, the following events happen: A chemical named acetylcholine, the neurotransmitter responsible for muscle contraction, is released from the motor neuron at the neuromuscular junction. This action causes changes in the permeability of the muscle cell membrane, which results in exchange of ions in and out of the muscle cell. Finally, a change in electrical potential is achieved. This change in electrical potential has the ability of propagating the length of the muscle fiber, causing the fiber to contract. What EMG records is this propagation of the change in electrical potential (Winter, 1990; Bruenger, 2008).

Which muscles are recruited in an exercise can be determined by EMG. The raw EMG signal only indicates when a muscle is active. However, this information could be very beneficial in understanding whether a physical activity incorporates specific muscles and the temporal sequencing of muscle actions. Since the evaluation and interpretation of the specific level of activity of muscles are difficult, the ideal use of EMG is for the determination of specific muscle recruitment and temporal muscle patterns.

Quantifying electrical activity from muscles is not easy. EMG signals are essentially made up of superimposed motor unit action potentials (MUAPs) from several motor units. The amplitude (magnitude) of the EMG signal only gives some indication about the relative amount of muscle recruited to perform certain activity. Many factors contribute to the understanding of the signal amplitude. Generally speaking, changes in amplitude of an EMG signal could be caused by an increased number of motor units being recruited, increased rate at which a motor unit is recruited, and/or synchronization of several motor units (Winter, 1990; Bruenger, 2008).

The size principle applies when motor units are recruited. Smaller motor units creating smaller action potential are more resistant to fatigue, and they are recruited first. As a muscle contracts more to generate greater force to perform an activity, the muscle fibers are stimulated more frequently. As the need for force increases, more motor units may be recruited. In the situation that multiple motor units are recruited, the action potentials of these motor units which are recorded by EMG are summated into a single wave. Unless fine wire EMG, a very delicate tool that can be used to monitor small muscles or even a single motor unit, is used, determination of which of these factors is causing the change in amplitude is impossible.

Some other factors also contribute to the magnitude of the recorded EMG signal. These included thickness of subcutaneous adipose tissue, muscle resting length, velocity of contraction, muscle mass/cross-sectional area, fiber type, age, gender, subtle changes in posture, interelectrode distance, and impedance of the skin. These factors make the evaluation of the muscle activity more complicated. The noise from equipment will also change the recorded magnitude. Likewise, the location of the electrodes on a muscle will also influence the amplitude. For a motor unit that is closer to the electrode with less soft tissue between it and the electrode, the recorded EMG signal will have a larger magnitude, compared to a same size motor unit that is farther away from the electrode and have more soft tissue between it and the electrode. Shallower muscles and even blood flow can influence the magnitude of the recorded signal. Another factor is the interpretation of the signal changes during a dynamic movement. The magnitude and frequency of the signal is dependent on muscle length and position, both of which are constantly changing during a dynamic movement (Robertson et al., 2004). Therefore, although a larger EMG signal implies that a greater effort was made to conduct an activity, EMG signals cannot be directly compared between individuals. Only in a same testing session in which the position of the electrodes are not changed, can results be interpreted to the individual being studied and compared to other movements performed in that session (Bruenger, 2008).

Even with the difficulties of understanding the EMG signal, it is still possible to quantify the amount of relative muscle exertion in an activity. For this to occur, the raw

EMG data must be modified. One of the most common means of modifying the signal is to rectify it. The mechanism behind this is that the action potentials create sinusoidal waves that, when averaged over time, would equal zero due to equivalent positive and negative portions of the wave. The modifying course consists of the negative signal being converted to positive value (full wave rectification) or being removed (half wave rectification). Because it contains the entire EMG signal, full wave rectification is usually the preferred method of modification. After the rectification, the signal can then be evaluated by several methods.

According to Winter (1990), there are multiple calculations that can be performed to interpret the EMG signal once the signal has been rectified. The most common method is integration. It is a method of calculating the area under the EMG signal as volt seconds. This can be done in two ways: to integrate for a set amount of time and define the time units, or, to integrate until a set amount of "energy" is reached prior to re-setting. A second method that is similar to integration is the use of a "linear envelope", in which a low pass filter is applied to the EMG signal and the resulting wave is a representation of the average EMG signal at any given moment. A third method does not involve rectification of the signal. It is named the root mean squared (RMS) amplitude. The following formula is used to calculate the root mean squared amplitude to estimate average muscle activity.

$$\mathrm{RMS}\ (\mathrm{EMG}(t) = (T^{-1} \int^{t+T} \mathrm{EMG}^2(t)\ dt\ )^{1/2}$$

In this formula, (t) represents each moment of time, t represents the initial time, and T represents total time evaluated (Robertson et al., 2004). By the use of any of these three methods, the electrical activity of the same muscle during different movements may be quantitatively compared.

Normalizing EMG data is an important technique for comparing subject-to-subject muscle activity. Each EMG instrument handles the amplification, filtering, and quantification of the EMG signal differently. For this reason, it is impossible to directly compare the values obtained on one EMG instrument with the values obtained on an instrument from another manufacturer. In order to make a comparison of EMG data from a same muscle on different individuals, EMG data must be normalized to Maximal Voluntary Isometric Contraction (MVIC). This method calculates EMG data from other muscle activities as a relative percentage of that from MVIC. The strength of this method is that it does not dependent upon the absolute microvolt values; it is only a relative comparison to a maximal effort. The primary problem with this method is that it relies on a voluntary component, without knowing whether or not the participant is giving his/her maximal exertion. In addition, it is hard to know if this maximal exertion replicates across time for this individual (Chan, C. A., 2010).

Due to the dynamic nature of the movements, interpretation of EMG signals is difficult. One method to control the amount of variability in the signal is to evaluate muscle contractions isometrically, so the resulting EMG analysis is assumed to reflect what occurs in a dynamic movement. However, this does not represent how the activity will be used in training and will not allow for interpretation of the muscle activity over the whole range of movement. A second method is to use isokinetic dynamometers to limit the amount of variability in the signal due to movement. The strength of this device is that it can keep the movement velocity constant and at the same time permit the movement through the full range of motion. However, the drawback of the device is that it can only be used for a limited number of movements. A third method is to set a guided cadence for the participants to perform the activity (Bruenger, 2008). The strength of this method is that it allows the participants to conduct movements freely without machine restrictions, making the performance more realistic to what occurs normally. However, whether the cadence is in accordance with or similar to the natural cadence of the movement is another question.

Therefore, it is very obvious that EMG is a useful tool in describing the muscle activity. The strongpoint is that it provides a unique method to detect and quantify the electrical activity from muscles and can describe the sequence. The drawback is due to scientists having a hard time accurately interpreting the EMG signal. Thus, caution is needed when trying to use EMG and interpret the signal. Moreover, comparison of studies should only be conducted when similar methods of regulation and recording are adopted.

EMG has been widely used to evaluate different training techniques, especially in the field of strength training, since muscle activation and development is the major purpose. As previously stated, most EMG investigations of the push-up were based on the independent variables being hand positions or body positions.

In push-up exercise studies, EMG remains one of the most important tools. Some beliefs about the effects of positions and variants on muscle activities are long held. Some of them have been testified, and some are just suggestions from coaches, waiting to be testified.

One belief from coaches is that the “incline” and “decline” position in both push-up and bench press is beneficial to specialized development of the pectoralis major muscle. Proponents of the incline and decline push-up insist that these two variants place different emphasis on the pectoralis major. Specifically, they conjecture that during the incline push-up, more muscle fibers from the lower pectoralis major are recruited; while, during the decline push-up, more muscle fibers from the upper pectoralis major are recruited. Many body building books also advocate the use of incline and decline bench presses to develop the middle, upper, and lower portions of the chest. However, Barnett et al. (1995) observed that the use of incline and decline presses did not significantly increase lower and upper pectoralis muscle recruitment. Similarly, in Glass and Armstrong’s study (1997), they also found that the upper pectoralis major was not less engaged in the performance of a decline press compared to an incline press. Since the anatomical mechanisms behind the bench press and the push-up and the incline and decline push-up variants are very similar, it is the author’s opinion that Barnett’s (1995) and Glass and Armstrong’s (1997) conclusion might be more valid. Moreover, one strength of these two studies is that, the rate of movement was controlled; a cadence of approximately two seconds (one second eccentric and one second concentric) was used to complete the lift and was monitored or regulated by metronome to verify it was consistent. This detail indicated a well controlled experiment and was what the author conducted in the current study.

Although most research focused on examination of the prime movers in the push-up exercises, some investigators (e.g., Lehman et al., 2008), noticed the important role that stabilizers played in maintaining the rigid body alignment. They examined the effects of an unstable surface on the scapulothoracic stabilizing muscle activity. In contrast to the belief that the rectus abdominis, external oblique, and internal oblique muscles played little role in the push-up, Howarth et al. (2008) found that the abdominal muscles actually dominate contributions to vertebral joint stiffness (VJS) during the standard push-up. The work of Freeman et al. (2006), who found moderate activation levels in the trunk flexors and lower activation in the trunk extensors, suggested that the standard push-up also challenged this musculature surrounding the lumbar spine in order to maintain a neutral spine posture. Thus, it is obvious that stabilizers play a critical role in performing the push-up exercise; and vice versa, the push-up exercise pays beneficial training back to these stabilizers.

The effects of hand positions on muscle recruitment level have been a hot topic. Studies have shown that different hand positions elicited different muscle responses. In Cogley's study (2005), three different bases were adopted: shoulder-width base, wide base, and narrow base. The EMG activity from the pectoralis major and triceps brachii showed that the narrow base hand position induced greatest muscle activation. This finding was consistent with that of Brickey (2008), who found the wide base variant was the easiest one with respect to muscular demands among the three variants. However, in a study of effects of hand placement on scapular stabilizers, Tucker et al. (2009) found the serratus anterior had greatest EMG activity for the wide base. In a recent study, Gouvali and Boudolos (2005) examined effects of normal, abducted (wide base), adducted (narrow base), posterior, and anterior hand positions on muscle activation. Conclusions indicated that the posterior hand position switched more muscle activation from the triceps brachii to the pectoralis major compared to the standard push-up. The anterior hand position induced more muscle activation for both muscles; and, the adducted hand position elicited more EMG activity than the abducted one.

Among the many push-up variants, Gouvali and Boudolos (2005) found that the knee push-up (modified push-up) generated less muscle activity in the pectoralis major and triceps brachii, proving a basis for why this variant is more suitable for weaker individuals. Beach et al. (2008) compared muscle activity of the abdominal wall and the latissimus dorsi in the standard push-up and suspended push-up; they concluded that the suspended push-up provided a superior abdominal muscle challenge. Consistent with the traditional belief, Free et al. (2006) demonstrated that a ballistic type push-up (i.e., clapping push-up in this study) caused more muscle activation and higher spine load. In this study it was also found that push-ups with an uneven hand placement (unsymmetrical) demonstrated more muscle activation in rectus abdominis and external oblique muscles on the side of forward hand placement, proving that Lee’s (2008) suggestion was reasonable. In order to find an exercise with minimal upper trapezius activation and maximal serratus anterior activation for treatment of poor scapular control, Ludewig et al. (2004) examined what they defined as the standard push-up plus, knee push-up plus, elbow push-up plus, and wall push-up plus. Their results showed that the standard push-up plus had the highest activation of the serratus anterior and lowest trapezius/serratus ratio during plus phases. Similar work was done by Martins et al. (2008) in order to help with rehabilitation of patients with shoulder dysfunction. Their study used two support bases (a stable base and a Swiss ball) and three exercises (wall push-up, bench press, and standard push-up). Results demonstrated that the standard push-up was a preferred variant with a lower trapezius/serratus ratio, which was consistent with Ludewig's (2004) conclusion. The unstable base had no effects on the ratio. Likewise, in the work of Lehman et al. (2008), who studied the push-up variant which involved the use of a Swiss ball, they found that an unstable support surface did not increase scapulothoracic stabilizing muscle activity. This finding implies that variants with an unstable surface will probably induce little muscle activity changes in the prime movers, such as the anterior deltoid and triceps brachii. One interesting fact is that, Lehman et al. (2008) compared the Swiss ball variant with the incline variant with an aim of maintaining a same height of body orientation; they also reversed the foot and hand positions of the participants by having them perform with their feet on either a bench or Swiss ball and hands on the floor. Their final findings revealed that elevating the feet above the hands appeared to have a greater influence on shoulder stabilizing musculature amplitude than the addition of a Swiss ball, which supported the hypothesis of the current author’s study.

Other researchers conducted EMG comparisons between the push-up exercise and closed kinetic chain exercises and exercises performed with an external device. For example, Rapp (2008) compared the EMG activity of the serratus anterior and the lower trapezius in indoor rock climbing, push-up plus, and press-up. He found no significant difference among these three exercises and suggested that rock climbing may be another effective closed kinetic chain activity that could be utilized by clinicians to strengthen these two muscles. Tucker et al. (2008) found that the muscle activation of the serratus anterior was very similar in the push-up exercise and in the use of the cuff link device. They concluded that the cuff link device may be an alternative exercise for individuals lacking the upper body strength.

It has been validated that in the standard push-up, knee push-up, and bench (incline) push-up that temporal order of prime mover muscle recruitment was the anterior deltoid, followed by the triceps brachii, trapezius, and clavicular portion of the pectoralis major (Hinson,1969). Hinson’s study also indicated that, in the same variants of the push-up, participants with less strength showed greater muscle activity. According to Lasjouri’s study (2004), a similar temporal pattern of muscle recruitment existed among the standard push-up and the modified push-up (knee push-up). It was evident from the studies by Hinson (1969) and Lasjouri (2004) that in the performance of the push-up, the anterior deltoid is an important muscle.

The only literature that involved a comprehensive study of the decline push-up is from Lear and Gross (1998) who focused on the perspective of rehabilitation. In this study, a push-up progression was adopted in which the standard push-up was compared to two decline variants. Results revealed that increasing the decline angle dramatically increased the EMG level of the serratus anterior and the upper trapezius. The investigators suggested that the significant increase observed was most likely related to the increase in the joint reaction forces caused by the increased loading through the glenohumeral joint. This study supports the clinical use of push-up progression to facilitate activation of the serratrus anterior and the upper trapezius during upper extremity rehabilitation, which implies that the decline push-up is valuable as a rehabilitation prescription. Additionally, the results of this study also suggested that appropriate push-up progressions for the general population should be differentiated from progressions performed by athletes, implying the necessity of further research on the decline push-up. Thus, Lear and Gross' (1998) study provided a very valuable basis for the current study.

After a thorough review of the related EMG literature, some beliefs are verified and conclusions can be drawn: a) anterior deltoid, triceps brachii, upper trapezius, pectoralis major, and serratus anterior are the most involved muscles in the push-up exercise; b) narrow base hand position is the most strenuous one in comparison to the push-up variants with wide and regular bases; c) unsymmetrical push-up places more emphasis on the side of forward hand placement; d) knee push-up has less requirements on strength; e) for participants with less strength or a history of injury associated with upper extremities, studies demonstrated greater muscle activation; and f) the push-up exercise produces beneficial development in the deltoid muscle.

Table 2.2

Summary of EMG Evaluations of the Push-up Exercise

Author (Date)	**Participants**	**Muscles Evaluated***	**Movement Regulation** in Seconds**	**Method of Evaluation**
Hinson (1969)	20 females	TB, D, PM, UT, SA, RA, EO	5 s/repetition	Photographic deflection
Anderson et al. (1984)	16 males 16 females	LD, PM, TB	3 s/repetition	Linear envelop
Lear & Gross (1998)	9 males 7 females	SA, UT, LT	Self-selected pace	RMS*** EMG signal normalized to MVIC****
Ludewig et al. (2004)	30 males & females	SA, UT	Metronome ECC: 2 s CON: 2 s	RMS*** EMG signal normalized to MVIC****
Lasjouri et al. (2004)	90 males	BB, D, PM, TB	Not specified	Not specified
Gouvali & Boudolos (2005)	8 males	TB, PM	Self-selected pace	Averaged RMS*** normalized to normal posture RMS***
Cogley et al. (2005)	11 males 29 females	PM, TB	ECC: 3 s CON: 3 s	RMS*** EMG signal normalized to MVIC****
Rapp et al. (2005)	8 males & females	SA, LT	Not specified	RMS*** EMG signal normalized to MVIC****
Stephanie et al. (2006)	9 males 1 female	RA, EO, PM, IO, LD, ES, TB, BB, D	Common pace slow ECC fast CON	RMS*** EMG signal normalized to MVIC****

Table 2.2 (cont'd)				
Howarth et al. (2008)	11 males	RA, EO, IO, LD	Metronome ECC: 1 s CON: 1 s	RMS*** EMG signal normalized to MVIC****
Lehman et al. (2008)	10 males	UT, LT, SA, BB	ECC: 2 s CON: 2 s	RMS*** EMG signal normalized to MVIC****
Matins et al. (2008)	20 males	SA, UT	6 s/repetition	Linear envelop and RMS*** EMG signal normalized to MVIC****
Tucker et al. (2008)	15 males 13 females	SA, MT, LT	Metronome ECC: 2 s CON: 2 s	RMS*** EMG signal normalized to MVIC****
Beach et al. (2008)	11 males	ES, EO, IO, RA, LD	Metronome ECC: 1 s CON: 1 s	RMS*** EMG signal normalized to MVIC****
Tucker et al. (2009)	19 males	SA, MT, LT	Metronome ECC: 1 s CON: 1 s	RMS*** EMG signal normalized to MVIC****

*TB = triceps brachii, D = deltoid, PM = pectoralis major, UT = upper trapezius, SA = serratus anterior, RA = rectus abdominis, EO = external oblique, IO = internal oblique, LD = latissimus dorsi,, LT = lower trapezius, BB = biceps brachii, ES = erector spinae, MT = middle trapezius

**ECC = eccentric, CON = concentric

***RMS = root mean squared

****MVIC = maximal voluntary isometric contractions

Other Facts

Gender topics

Some studies focused on gender differences in the performance of the push-up exercise. Anderson (1984) investigated the effects of gender on muscle activities. He found that women produced greater mean EMG activity than men in the latissimus dorsi, pectoralis major, and triceps brachii at all three sitting positions (the standard wheelchair position, mid-position, and elevated sitting position). This result was reasonable based on the outcome that participants with less strength generated more muscle activity.

Other studies concentrated on female performance of the push-up exercise because the validity and objectivity of this exercise for women were seldom explored due to the traditional belief that “only males need to do push-ups.” Hinson (1969) studied the knee push-up in two groups of women. One group could perform ten or more standard push-ups, and the other group could perform no more than five knee push-ups. She found that the weaker group consistently showed greater muscular activity. Objectivity, reliability, and validity of the knee push-up for college age women were examined by Heather and Baumgartner (2004). A very high interscorer objectivity for the knee push-up was found, and the validity and reliability of these scores were acceptable. The researchers suggested that the knee push-up was probably more appropriate for lower strength level college age women. Likewise, Cucina and McCahan (2003) compared the modified push-up (knee push-up) and the standard push-up for college age women using five raters to give scores for both push-ups. A Pearson correlation score of 0.849 was obtained, which indicated a strong positive linear relationship between these two push-ups. The investigators suggested that if women were conditioned effectively for both core and upper body strength, they could potentially transit from the modified push-up to standard push-up. However, the investigators' final discussion seemed somewhat conservative. They stated that without performance norms for women of average fitness, there was little encouragement for them to perform the standard push-up and gain upper body strength.

Injury- and rehabilitation-related topics

The study of the push-up is worthwhile considering this exercise is a useful rehabilitation tool. It may aid in recovery from certain types of upper extremity injuries such as shoulder joint dislocation, elbow joint reconstruction, and soft tissue problems. On the other hand, research on different types of push-ups may aid in the understanding of injury mechanism, thus helping to prevent some upper extremity injuries beforehand.

Effects of four hand positions during the push-up were examined on spinal cord injured patients (Kotani & Tokuhiro, 2002). The hand pressure gave an indication that in a normal situation, the order of magnitude of force from greatest to least should be

Fz (vertical force), Fx (anterior-posterior force), and then followed by Fy (medial-lateral force). In a special hand position (finger spread) in which the order of magnitude of force changed to Fz, Fy and Fx, patients with neurological injury levels above T4 and patients with injuries between T5 and T10 without spinal instrumentation could not push themselves up. This phenomenon demonstrated that during the push-up exercise the spinal muscles played an important role in lateral balancing, and thus some revised push-up types may be of help with the rehabilitation of spinal muscles. Hand pressure was also studied to find an effective way to handle the push-up action of the hands against wheelchairs. The results showed that Fx (anterior-posterior force) and Fy (medial-lateral force) appeared earliest and remained longest during the most unstable hand position. The conclusion was that Fx and Fy were considered to be good indicators of body balance during the push-up exercise and the push-up device used for elevating hand position was very helpful with the performance for patients sitting in wheelchairs (Ikawa & Tokuhiro, 1995).

One study (Lear & Gross, 1998) recommended incorporating push-up progression (a series of 3 push-up variants with a different decline angle each) into upper extremity rehabilitation for advanced training of the scapular stabilizers. This research was somewhat novel since no documents existed to demonstrate changes in the level of muscle activation when push-up progressions were performed. Since the EMG data revealed a statistically significant difference in muscle activity when the feet were elevated gradually, the final conclusion supports the clinical use of push-up progressions to facilitate activation of the serratus anterior and upper trapezius during upper extremity rehabilitation.

Strengthening the serratus anterior is used in prevention and treatment programs for individuals with poor scapular stability and control. In certain clinical cases, exercises substantially activating the serratus anterior with minimal upper trapezius activation are preferred. Ludewig et al. (2004) compared four push-up variants (standard plus, elbow, knee, and wall) in two groups of participants (grouped as healthy or with mild shoulder dysfunction). They concluded that in clinical cases, where excess upper trapezius activation or imbalance of serratus anterior and trapezius activation occurred, the push-up plus was an optimal exercise. The standard push-up plus showed both the highest serratus anterior activation and lowest upper trapezius/serraturs anterior ratio for both groups and all phases. A similar research was conducted by Martins et al. (2008). A stable base of support and an unstable base of support were utilized in the study and three exercises (bench press, wall push-up, and standard push-up) were compared. The results showed that the standard push-up had obvious lower trapezius/serraturs anterior ratio than the wall push-up; the bench press on a stable surface was the exercise most preferred for serratus anterior muscle training in patients with serratus anterior weakness.

In the early stage of shoulder rehabilitation, closed kinetic chain exercise have been shown to improve joint proprioceptive sense and stability and decrease tensile stresses at the glenohumeral joint. So Rapp et al. (2005) compared the serratus anterior and the lower trapezius muscle activity in three closed kinetic chain exercises (indoor rock climbing, push-up plus and press-up). The results of this pilot study suggested that indoor climbing walls may be similar to traditional closed kinetic chain exercises in recruiting both the serratus anterior and lower trapezius. Therefore, rock climbing may be another effective closed kinetic chain activity that could be utilized by clinicians to strengthen these muscles.

Lou et al. (2001) studied the elbow joint load and possible injury mechanisms in three forearm positions (neutral, internally rotated 90 degrees, and externally rotated 90 degrees) used for performing the push-up. They found that the loading biomechanics of the elbow joint differed with various forearm rotations. Their conclusions indicated that push-ups with hands in an internally rotated position resulted in greater shear forces, thus should be prevented so as to avoid excessive shear forces or moments. Through a very similar research on one-hand push-up, Chou et al. (2002) provided a useful suggestion about prevention of elbow injuries during forward falls. They found that the peak valgus shear force with the hand externally rotated was 50% greater than that with internally rotated and neutral. Thus, outward rotation of the hand is a stressful position that should be avoided during one-hand push-up to reduce the risk of elbow injuries. Lou et al.'s (2001) study provided a basis for the current study in determination of the hand orientation (30 degrees of external rotation).

Relationship and prediction topics

The push-up exercise is also utilized to predict upper body strength and endurance, and to predict the performance in other exercises.

Mayhew et al. (1991) evaluated the feasibility of using push-ups to predict upper body strength, which was represented by one-repetition maximum (1 RM) concentric bench press performance. They noted that push-ups were not an accurate reflection of upper body strength in young males due to the large error. Likewise, Invergo et al. (1991) recruited 144 participants to compare the effectiveness of push-ups and absolute muscular endurance (YMCA bench press test) for predicting the maximal weight that could be lifted in the bench press exercise. Results of a multiple regression analysis revealed that bench press absolute endurance was more effective for predicting bench press strength, suggesting that absolute muscular endurance in some cases may provide a feasible alternative to the one-repetition maximum in the assessment of maximal lifting capacity.

Sakamaki (1983) tried the burpee push-up test as a simple method of measuring endurance. To resolve the problem of lack of special apparatus and other difficulties that arise in the step test, the researcher attempted to find a simpler alternative for measuring endurance. During the burpee push-up test, he found that the heart rate and its tendency to increase during exercise, and the heart rate and its tendency to decrease during recovery were very similar to that in the step test. In addition, the index whereby endurance was judged in the burpee push-up test was almost the same as that of the step test. In conclusion, the researcher considered it appropriate that endurance can be estimated by using the burpee push-up test instead of the step test.

Comparison of dynamic push-up training and plyometric push-up training on upper body power and strength was made on two criterion measures. One was the maximum weight for one-repetition of a sitting chest press, and the other was a medicine ball put for maximum distance. The plyometric push-up group experienced significantly greater improvements than the dynamic push-up group on the medicine ball put, while there was no significant difference between groups for the chest press (Vossen et al., 2000).

Esco et al. (2008) conducted an interesting study exploring whether selected anthropometric measures (i.e., skinfold thickness) were associated with sit-ups and push-ups performance. They found that there were a number of selected health related anthropometric variables (i.e., skinfold at the thigh and circumferences of the abdomen, waist, and hip) that accounted significantly for, and are predictive of, sit-up and push-up tests.

Additionally, some researchers did a lot of work to normalize certain push-up variants and/or examine the objectivity, reliability, and validity of some revised push-up test protocols (McManis et al., 2000; Romain & Mahar, 2001; Baumgartner et al., 2002; Baumgartner et al., 2004).

In summary, previous researches give a deep insight into the methods of exploring the push-up exercise, providing a strong basis for the current study.

CHAPTER 3: METHODS

CHAPTER 3 consists of the specific procedures and methods that were used in this study. It begins with descriptions of the research design, participants, selection criteria, recruitment, sample size; proceeds to descriptions of instrumentation and testing procedures; and concludes with data analysis and management.

Research Design

This study was a one group repeated measures design. The design was quasi-experimental, because there was no control group. The formal experimental approach consisted of three phases: participant information and preparation, familiarization, and performance testing (see Table 3.2).

The purpose of the participant information and preparation phase was to inform the participants of the details and steps to be used in the experimental process and collect completed consent forms and questionnaires. The second investigator then did anthropometric measures on the participants.

The second phase provided a chance to participants to warm up and stretch. The second investigator then prepared the participants for the electromyographic (EMG) collection. After these steps, the participants made few practice trials of the incline and decline push-up. They selected freely from provided body angles and cadences.

The purpose of the final phase was to conduct data collection for later analysis and interpretation. This consisted of measuring hand forces from a force platform, elbow joint angle from an electrogoniometer, and muscle activities of pectoralis major, triceps brachii, deltoid, and upper trapezius from EMG equipment. These measures were collected during the performance of sets of incline and decline push-ups at five body angles and three performance cadences. This resulted in a total of 15 push-up sets. For a combination of a body angle and a performance cadence (one set), three repetitions were performed, resulting in 45 total push-up repetitions (see Table 3.1).

Table 3.1

Five Body Angles and Three Cadences of Performances of Push-up Variants

	Decline Push-up (-10°)	Decline Push-up (0°)	Standard Push-up (≅15°)	Incline Push-up (30°)	Incline Push-up (45°)
Cadence 1/20 beats/min	3 Rep	3 Rep	3 Rep	3 Rep	3 Rep
Cadence 2/30 beats/min	3 Rep	3 Rep.	3 Rep	3 Rep	3 Rep
Cadence 3/60 beats/min	3 Rep	3 Rep	3 Rep	3 Rep	3 Rep

A non-random sample of adults from the greater Michigan area was recruited. All participants signed a consent form prior to participation in the study (see Appendix A).

The purposes of the study were to investigate the influences of the independent variables (body angle and cadence) on the: a) three maximum hand forces experienced at the right hand; b) the perpendicular force Fz pattern; c) the relatively most active muscle among the pectoralis major, triceps brachii, deltoid, and trapezius; and d) activation patterns of the pectoralis major, triceps brachii, deltoid, and trapezius in the push-up exercises.

Participants

Participants were all adults, mainly consisting of college students (16 males and eight females), who were from Michigan area and had at least six months of recent experience of performing the push-up. Both males and females were chosen because the push-up is included in exercise and prescription programs for both genders. Each participant was contacted by telephone before the testing to make sure they did not have heath problems and current injuries. All participants were free from upper extremity and shoulder injuries and any other injuries that may adversely influence their performance of the push-up during the testing (see Appendix C).

Selection Criteria

Adults from the greater Michigan area were the population if they meet the following selection criteria: a) have at least six months experience of performing push-ups; b) are free from upper extremity and shoulder injuries and any other injuries that may adversely influence their performance of the push-up; and c) have the ability to perform 45 push-ups (15 sets of three push-ups with breaks between sets). All participants were telephoned to make sure they did not have health problems and current injuries. Two questionnaires (see Appendix C) were distributed to screen participants for injuries to the trunk and extremities (shoulder, arm, elbow, forearm, wrist, hands, hip, thigh, knee, shank, ankle, and foot) that may adversely influence their performance of the push-up. A consent form was signed in order for a volunteer to participate in this study (see Appendix A).

Recruitment

The current investigator and colleagues solicited students in eight undergraduate Kinesiology courses. Flyers (see Appendix C) were posted in campus intramural buildings, for example, IM West, IM East, and IM Circle Building, to recruit college students and faculty. Flyers were also distributed to off-campus fitness centers in the greater Lansing area; for example, Hanna Fitness Center to recruit volunteers. After receiving permission from potential participants and course instructors and coaches, dates and places were arranged for the current investigator to make presentations to the volunteers about the study to inform them of the details and to answer questions. Candidates who were interested then left their contact information on a contact information form. A total of 153 volunteers indicated their willingness to participate in this research, which consisted of the target pool. The current investigator selected six potential participants from each class and twelve from flyer responders to contact via phone calls. Therefore, 60 out of 153 volunteers were contacted via phone. Twenty seven out of these 60 were excluded due to various reasons (like schedule conflict, no experience, and injury history); nine out of 60 did not show up in their scheduled session due to traffic and other reasons. Finally, 36 participants were excluded and 24 participants without health problems and current injuries completed the experiment. All participants signed a consent form in compliance with Michigan State University policies protecting human subjects.

Sample Size

Two methods were combined together to determine the sample size in this study: power analysis by G Power software and imitating a sample size of similar studies. A minimum power level of 0.8 or greater was obtained on all dependent variables with the sample size of 24. Similar studies had sample sizes of ranging from one to 20 participants. An average number of ten participants was very common (An et al., 1990; An et al., 1992; Chou et al., 2002; Donkers et al., 1993; Hinson, 1969; Howarth et al., 2008; Ikawa & Tokuhiro, 1995; Kotani & Tokuhiro, 2002; Lou et al., 2001; Rapp et al., 2005).

Instrumentation

Instrumentation in this study included a force platform, electromyography (EMG), electrogoniometer, anthropometer, metronome, CRAFTSMAN multifunction digital level, angle adjustment box, performance board, and Maximum Voluntary Isometric Contraction (MVIC) test bench.

Force platform

During the performance of the incline and decline push-ups, participants placed their right hands on an Advanced Mechanical Technology Incorporated (AMTI) force platform model OR6-5-1000 (AMTI, Watertown, MA) (see Figures 3.1 and 3.2). A wooden plate of 1.2 (width) X 2 (length) meters was built for this study as a performance board (see Figure 3.1). The force platform was attached to the surface of the performance board to collect perpendicular and horizontal (anterior-posterior and medial-lateral) surface reaction force data from the interface between the right hand and the platform surface. Due to the incline and decline body angle, the perpendicular and horizontal surface reaction forces were defined relative to the surface of the performance board. The perpendicular surface reaction force refers to the force that is perpendicular to the surface of the force platform and performance board, and the horizontal surface reaction forces refer to the anterior-posterior and medial-lateral forces that are parallel to the surface of the force platform and performance board. Prior to the data collection, all three forces of the force platform were statically calibrated. The calibration was done by putting different weights on the surface of the force platform, and the increments (30lbs) of the weight covered the entire range (0-150lbs) of expected force values. A calibration form was attached in Appendix B indicating there were no large differences between an angled force platform (30^0 and 45^0) and flat force platform (0^0) in the condition of 0 loads. This meant that collecting force data with an angled force platform would not induce significant error compared with a flat force platform. Data were collected at 500 Hz.

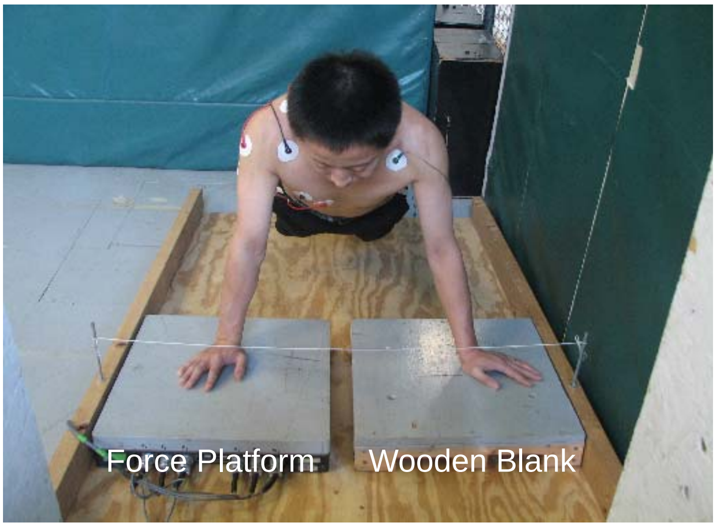

Figure 3.1 Arrangement of the force platform and performance board

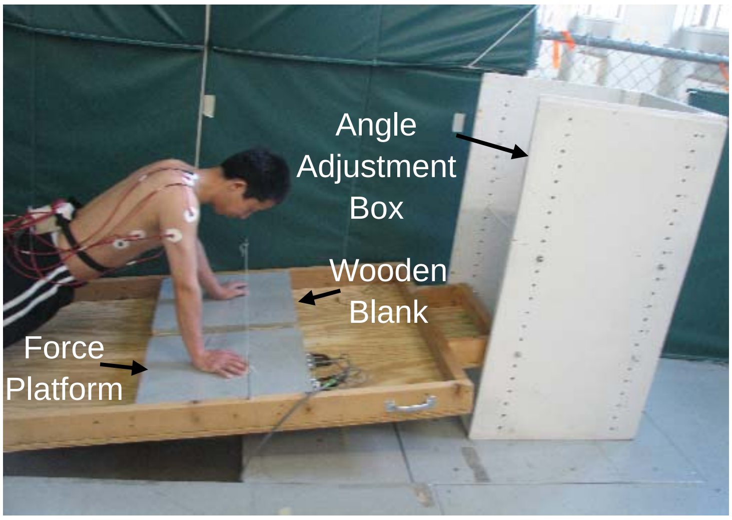

Figure 3.2 Arrangement of the force platform and angle adjustment box

Electromyography equipment (EMG)

Muscle activity was recorded using surface electromyography (EMG). A MYOPAC telemetric system (Run Technologies, Mission Viejo, CA) was adopted in the study to collect EMG data. EMG was recorded on the right pectoralis major, triceps brachii, deltoid, and upper trapezius muscles. Additionally, a single electrode was placed on the left clavicle to serve as a ground reference. The electrode placement was illustrated in Figure 3.3-3.5. Prior to attaching the surface electrodes, the skin of the participants was prepared by shaving, cleaning the dead skin with an abrasive pad, and rubbing with alcohol to reduce electrical resistance. Silver chloride electrodes (Ambu Blue Sensor SE, SE-00-S50, Ballerup, Denmark) were attached along the muscle bellies of the selected muscles, parallel to the muscle fiber direction. The electrodes were secured to the skin with tape. The appropriateness of electrode placement was confirmed with a manual muscle test for each muscle (Gouvali &

Boudolos, 2005).

A portable EMG belt unit was strapped around the waists of participants. Electric leads were then attached from the portable belt unit (see Figures 3.3 – 3.5) to the electrodes and the signals were transferred to the MYOPAC system via optic cable. Totally eight channels were used for the EMG system, the force platform system, and the electrogoniometer. A sampling frequency of 500 Hz was set for the EMG. Gain was set at 1000 while input impedance was one megaohm and common mode rejection ratio was 110 dB minute at 60 Hz.

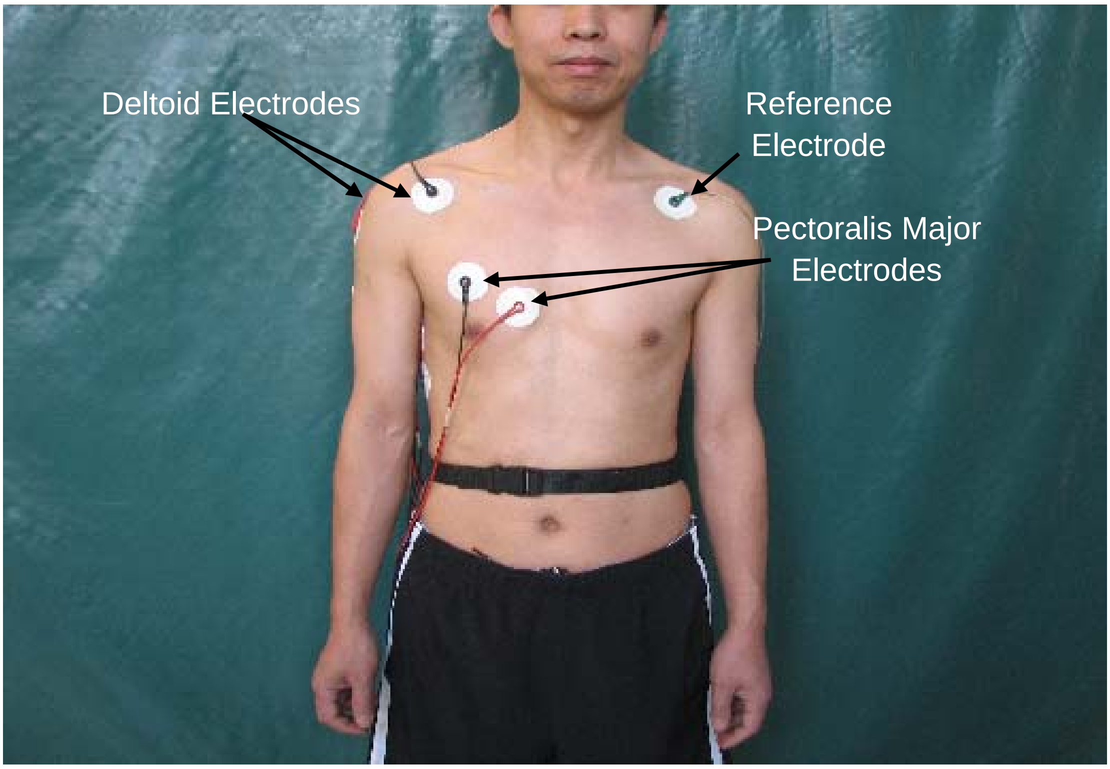

Figure 3.3 Anterior plane view of EMG electrode placement

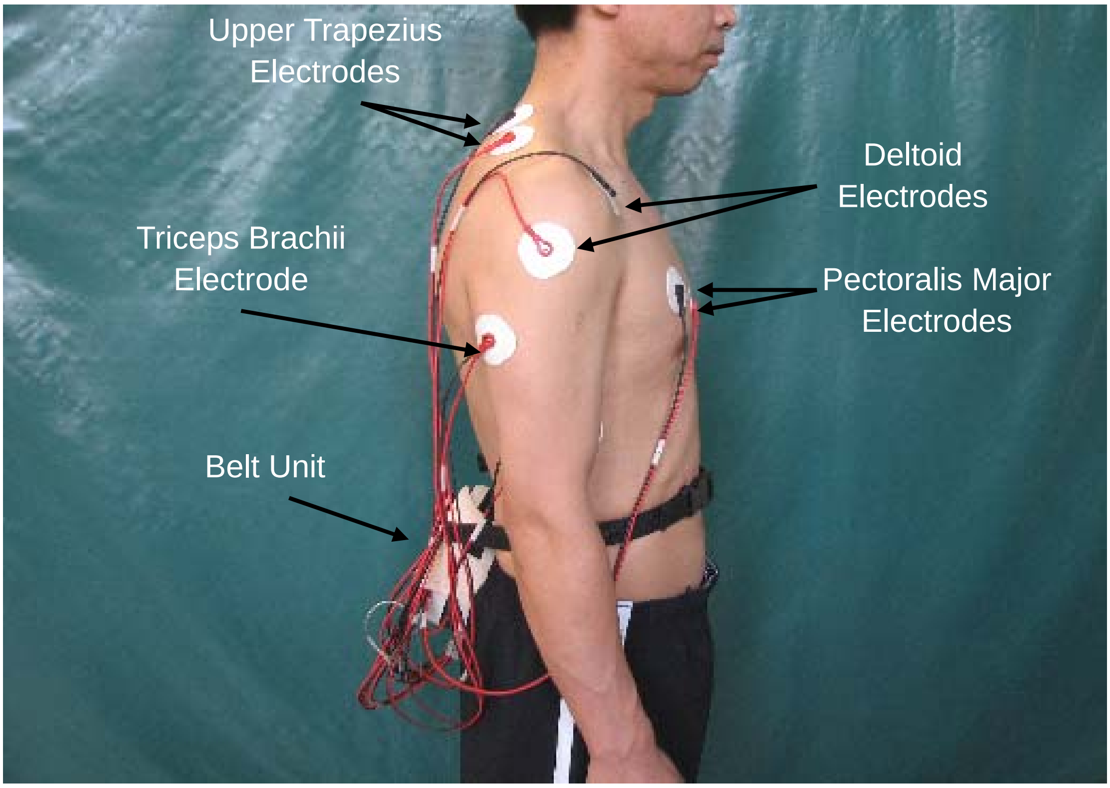

Figure 3.4 Sagittal plane view of EMG electrode placement

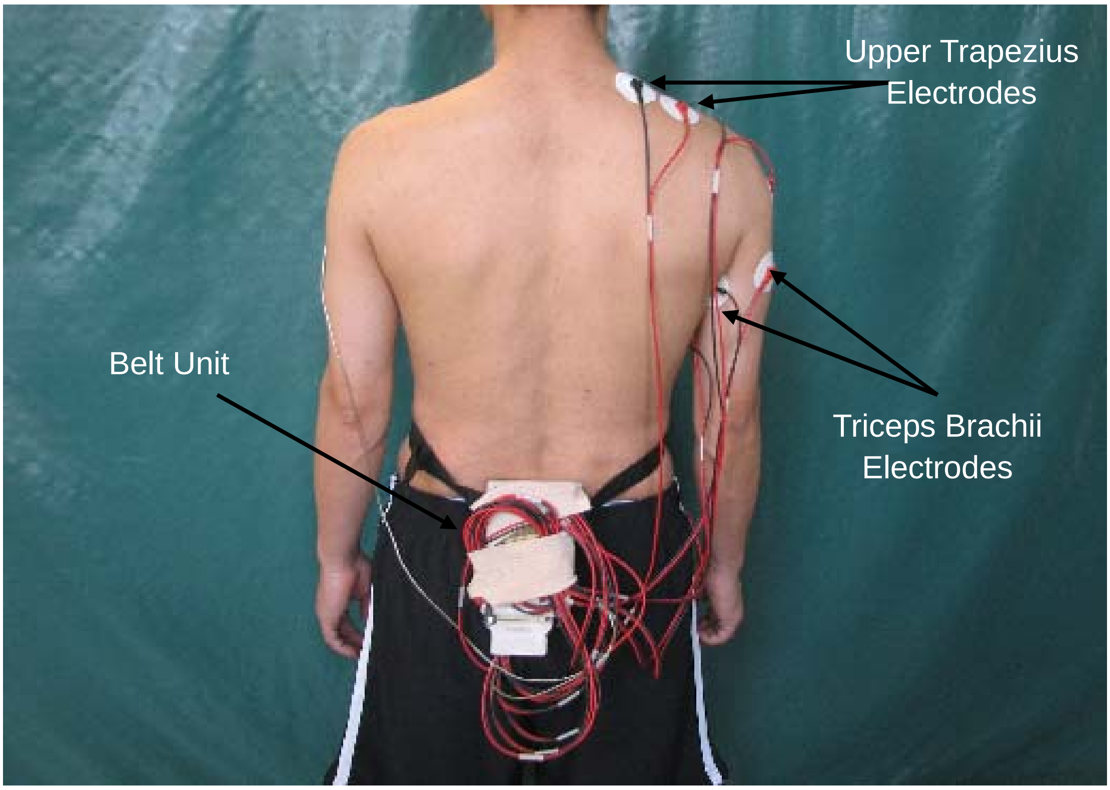

Figure 3.5 Posterior plane view of EMG electrode placement

Electrogoniometer

An electrogoniometer is an instrumentation that provides an analog output signal for measuring the relative angle between two segment members of a joint (e.g., arm and forearm at the elbow joint). In this study, the elbow joint angle was measured during every trial as a reference system to locate different events in the incline and decline push-ups. The electrogoniometer for the knee joint in the Biomechanics Research Station was revised into an elbow joint electrogoniometer to finish this task by a research specialist Dr. Li Guojing from Mechanical Engineering Department at MSU. The revision of the electrogoniometer was completed in the professional mechanical laboratory (professor Liu Dahsing) located in the MSU Scientific Park, and Dr. Li is an experienced mechanical specialist with concentration in force sensors design and mechanical devices development. Two sets of test were conducted in the mechanical laboratory, each including test of electrical signals input and output, accuracy of the input and output, test range of the electrogoniometer, and a simulating test on human elbow joint. Two additional sets of test were repeated in the Biomechanics Research Station. The working mechanism of an electrogoniometer is that an input signal, which is an angle change, is converted to an electrical signal by a potentiometer and recorded as an output on a computer. The core part of an electrogoniometer is a potentiometer. As long as the potentiometer has an acceptable rang and accuracy, there is no problem with revising a knee joint electrogoniometer to an elbow one. In addition, the knee and elbow joints have very similar range of movement.

The calibration of the electrogoniometer was conducted prior to testing of each participant. An angle of 180 degrees corresponded to a straight alignment of the arm and forearm, and an angle of 90 degrees corresponded to a right angle alignment of the flexed elbow joint.

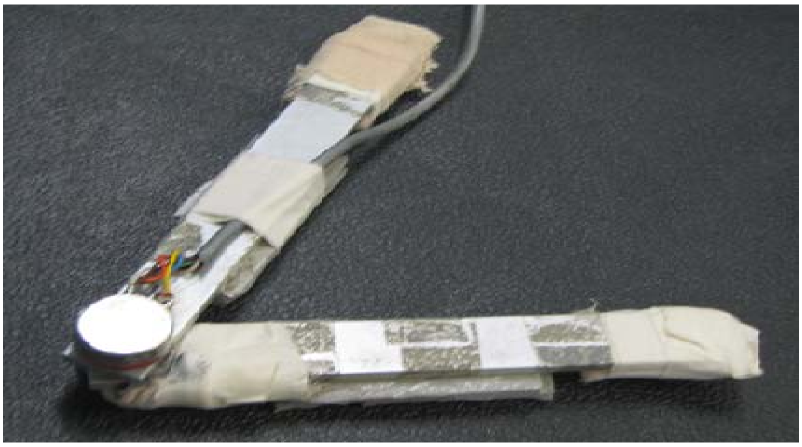

Figure 3.6 Electrogoniometer

Anthropometer

In order to get a general description of the participants' body parameters and to better understand the final experimental results and limitations, anthropometric data were collected prior to the formal testing. The anthropometric instrumentation included a scale, stadiometer, and anthropometer. Participants' body weight, standing height, sitting height, arm length, forearm length, hand length, wrist width, elbow width, and bi-acromion breadth were measured in step four of phase one (Participant Information and Preparation Phase). The following procedures described in detail how the anthropometric data were collected by the current investigator.

Figure 3.7 Anthropometer

1. Body weight: Body weight was measured on a standard scale to the nearest 0.1 pounds while the participants were in tight shorts and tight T-shirt (without shoes).
2. Standing height: Standing height was measured on a standiometer to the nearest 0.01 meters when participants stood erect with heels placed together and body weight distributed evenly on both feet. Participants were instructed to look straight forward with the head positioned in the Frankfort plane, and upper extremities hanging freely on both sides of the body. During this measurement, participants were asked to take in a deep breath and get as tall as possible without the heels leaving the floor. To depress the hair, the sliding bar of the stadiometer was brought down on the vertex of the head with sufficient pressure (Bruenger, 2008). The distance between the ground and vertex of the head was the standing height.
3. Sitting height: Sitting height was measured to the nearest 0.01 meters when the participants were sitting on a bench with their backs and hips against a vertical

wall. Participants were asked to sit as upright as possible without the hips leaving the bench and take in a deep breath during the measurement. To depress the hair, the sliding bar of the short anthropometer was brought down on the vertex of the head with sufficient pressure. The distance between the bench and the vertex of the head was the sitting height.

4. Arm length: Arm length was measured to the nearest 0. 1 centimeter by having the participants stand erect with a fully straightened right upper extremity. During the measurement, the short anthropometer was used to measure the distance between the center of the shoulder joint and the center of the elbow joint to determine proper arm length.
5. Forearm length: Forearm length was measured to the nearest 0. 1 centimeter by having the participants stand erect with a fully straightened right upper extremity. During the measurement, the short anthropometer was used to measure the distance between the center of the elbow joint (crease of the elbow) and the center of the wrist joint (crease between the forearm and hand) to determine the forearm length.
6. Hand length: Hand length was measured to the nearest 0.1 centimeter by having the participants fully straighten and raise their right hand to the height of the chest with the palm up. The distance from the tip of middle finger to the center of wrist joint (wrist crease) was the hand length.
7. Wrist width: Wrist width was measured to the nearest 0.1 centimeter by having participants fully straighten and raise the right forearm to the height of the chest

with the palm up. The short anthropometer was used to measure the distance between the furthest lateral side and the furthest medial side of the wrist.

8. Elbow width: Elbow width was measured to the nearest 0.1 centimeter with the short anthropometer by having the participants fully straighten the upper extremity with the palm up. The distance between the furthest lateral sides and the furthest medial side on the elbow crease was the expected elbow width.
9. Bi-acromion breadth: Bi-acromion breadth was measured to the nearest 1 inch by having the participants stand erect with both upper extremities hang freely on both sides of the body. Participants distributed the body weight evenly on both feet, with feet shoulder-width apart and with their backs to the examiner. The acromion processes were palpated with the examiner's index finger. In order to get the greatest shoulder breadth, pressure was applied to compress the skin and adipose tissue. The distance was measured using the short anthropometer (Bruenger, 2008). The measured distance was the expected bi-acromion breadth.

Metronome

A metronome software (Crystal Metronome 1.0.0 by MIL Software) was installed on the lab computer in Biomechanics Research Station to mark time intervals and control the cadence of the performance of push-ups. This software is a full-featured, high quality metronome for Windows with 23 configurable sounds. It has the function of subdivisions, which includes eight notes and triplets. Every beat of this metronome is accurate to better than one ten thousandth of a second. In this study the pace was set at, 20, 30, and 60 beats/minute. This corresponded to 10, 15, and 30 repetitions of the push-up per minute. The participant was instructed to perform the incline and decline push-up by matching every beat to the completion of each eccentric and concentric phase. Each subject was also given practice to match their movement patterns with the sound patterns prior to the formal testing phase.

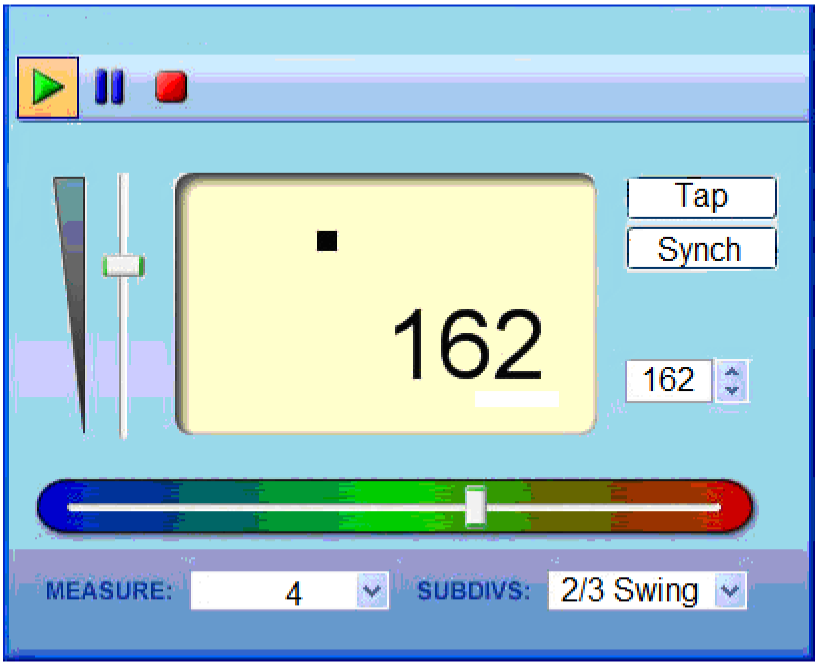

Figure 3.8 Crystal Metronome screen display

Digital level

The CRAFTSMAN multifunction digital Level (Sears, Roebuck and Co., Hoffman Estates, IL) was a ten-inch laser instrument that was used to measure the incline and decline angle of the body in this study. It was mounted on a 1.5 meters aluminum bar by threaded screw (see Figures 3.9 and 3.10). The small LCD digital display window on the device accurately indicated the angle that the device was oriented relative to the laboratory horizontal. During measurement, the bar was aligned to connect the centers of the ankle and shoulder joints. The value of the angle that appeared in the window of the digital level was the incline or decline angle of the body. The tool does not need to be calibrated, and is accurate to 0.01 degrees.

Figure 3.9 CRAFTSMAN multifunction digital level

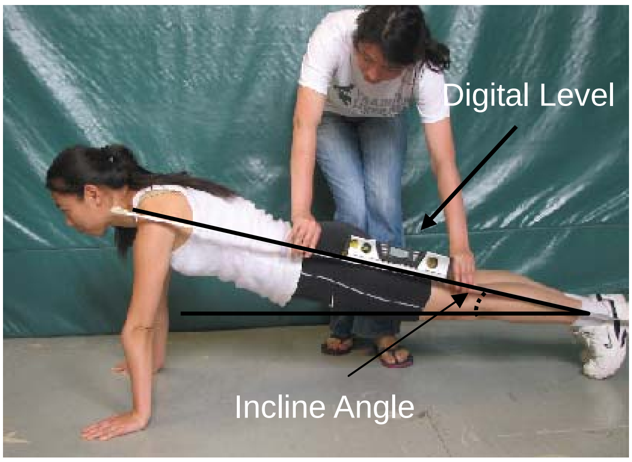

Figure 3.10 Measurement of the body angle with the digital level

Angle adjustment box and performance board

A wooden box named angle adjustment box was built to facilitate changes in the incline and decline angle of the body for the performance of the push-up exercise (see Figure 3.11). A row of 23 numbered holes, each one inch distance apart, on each side was used to support a steel bar, on which the performance board was hung. By switching between the two rows of holes, the angle of the performance board was adjusted, so the incline angle used for the push-up was changed. For example, row #21 was corresponding to about 45 degrees of the incline angle. For participants with different heights and arm lengths, row #19 - #23 was typically selected to make the body angle more precise.

To change the decline angle, the performance board was not needed. The two rows of 23 numbered holes on the angle adjustment box were used to support two steel bars, on which a rectangular wooden support was placed to support the participants' feet (see Figure 3.12). By changing the height of the bars via the rows of numbered holes and placing the wooden surface on the two steel bars, the decline angle was changed. For example, row#16 was corresponding to approximately -10 degrees of the decline angle. For participants with different heights and arm lengths, row#14 - #18 was typically selected to make the body angle more precise.

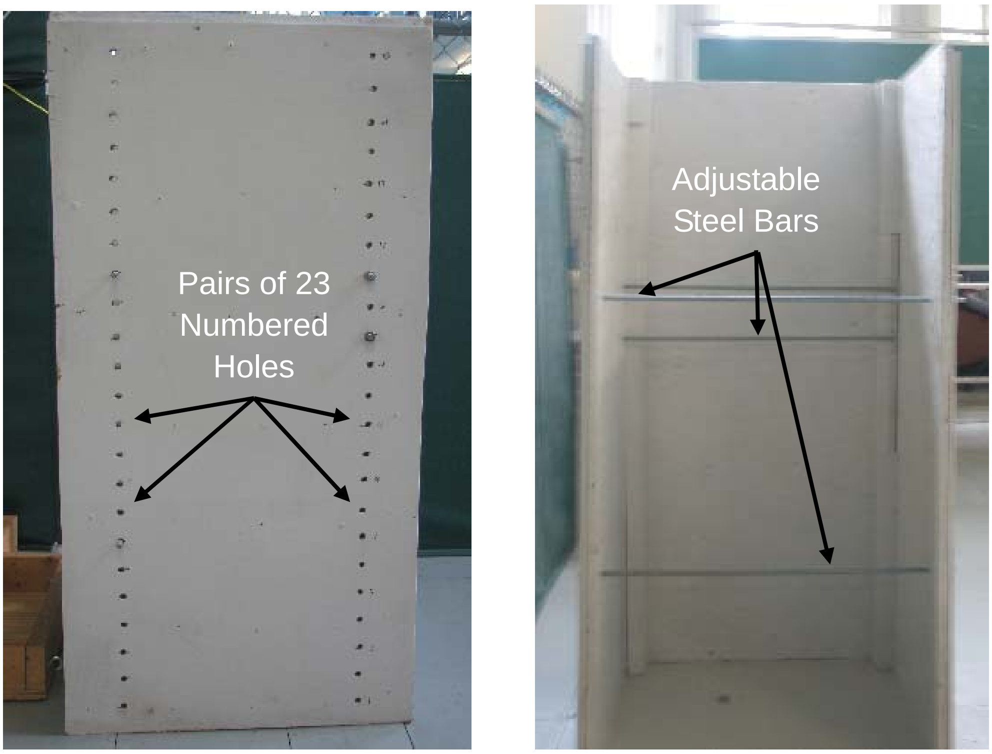

Figure 3.11 Side and front view of the angle adjustment box for change of the incline angle

Figure 3.12 Side and front view of the angle adjustment box for change of the decline angle

A wooden board named performance board was built with a force platform attached on the right surface and a wooden blank on the left surface. There were two hooks on the head of the performance board so it could be hung on a steel bar placed through a pair of holes on the angle adjustment box to change the incline and decline angle for the performance of the push-up (see Figure 3.13). Two handles (see Figure 3.13), one on each side of the performance board, aided the researchers in moving the board during testing.

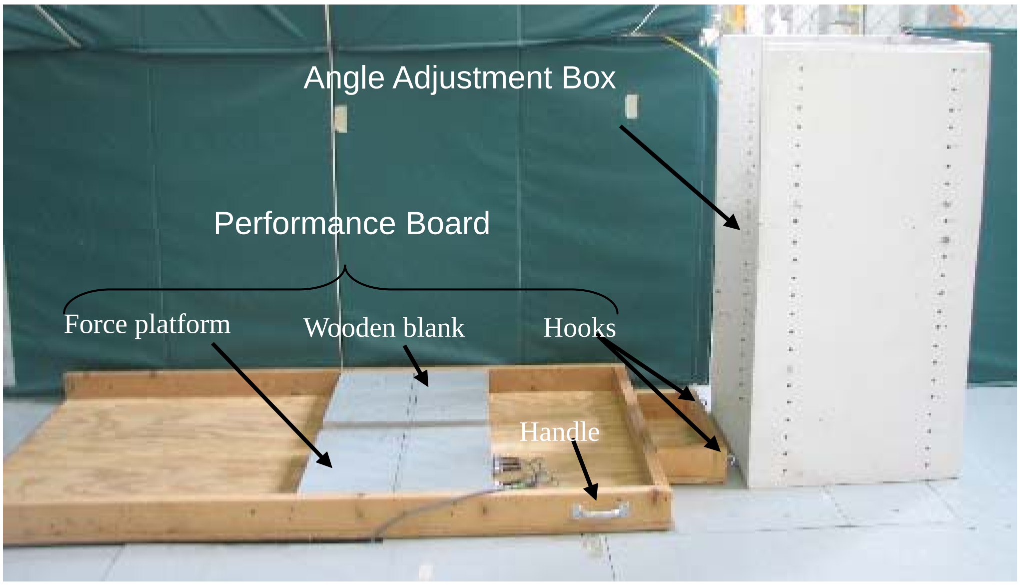

Figure 3.13 Sagittal view of the performance board and angle adjustment box

Participants performed the testing on the performance board and aligned their hands with the orientation system drawn on the force platform and wooden blank (see Figure 3.14). A horizontal line was drawn on the force platform and wooden blank radiating from the centers of the performance board and wooden blank. Increments of units of 0.5 inches were marked on the horizontal line to be used for recording proper hand placement for each performance of the push-up. During the performance of the push-up, the participant placed the medial edge of the thumbs at the same coordinate points on each side of the horizontal line and aligned the middle fingers to the oblique 30 degrees lines drawn on the force platform and wooden blank. The distance between the edges of two thumbs was equal to the bi-acromion breadth, which means, a 100% shoulder-width was being used.

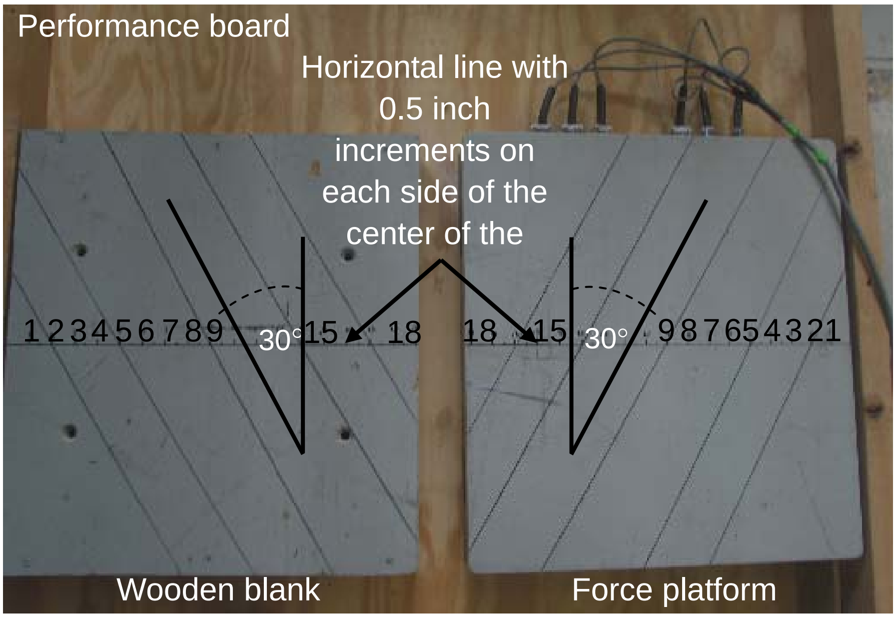

Figure 3.14 Orientation system (30 degrees parallel lines) for the hands on the force platform and wooden blank with horizontal line increments for determining spread between hands

Maximum Voluntary Isometric Contraction (MVIC) test bench

A MVIC test (six seconds) was conducted on a weight training bench (see Figure 3.15 and 3.16). A barbell bar was placed on the supporting parts of the bench. Instead of using free weights, the bar was restrained to the bench legs by clamps and two steel cables approximately three meters in length. Prior to the MVIC test, the participant lied in a supine position on the surface of the bench, with hands 150% shoulder-width apart pushing on the bar; and the angle at the elbow joint was adjusted to 90 degrees for each participant by changing the cable length through the clamps. During the MVIC test, the participant pushed the barbell bar with as much force as possible for six seconds. EMG data of this maximum isometric contraction for the pectoralis major, triceps brachii, deltoid, and upper trapezius were recorded at 500 Hz as a reference, and all EMG data collected during the formal performance testing phase were later normalized to the EMG data collected from this test.

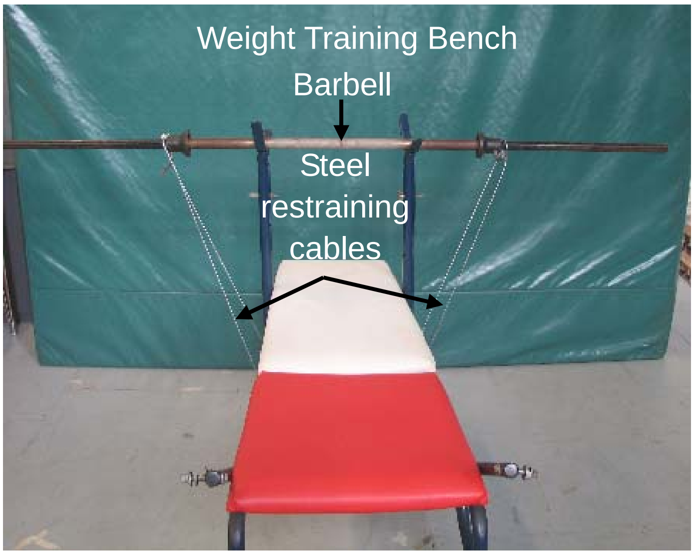

Figure 3.15 Anterior view of the Maximum Voluntary Isometric Contraction (MVIC) test bench

Figure 3.16 Example performance of the Maximum Voluntary Isometric Contraction (MVIC) test

Testing Procedures

Table 3.1 provided an outline of the testing procedures. Three phases were gone through by each participant. In each phase, steps were arranged in a prescribed order and this order was strictly followed during the testing.

Table 3.2

Outline of Experimental Sequences and Procedures

Phase one: participant information and preparation phase (30 minutes)
1. Explaining about the study and next steps
2. Signing and returning of consent forms
3. Filling out questionnaires
4. Conducting anthropometric measures
Phase two: familiarization phase (60 minutes)
1. Warming up
2. Stretching
3. Shaving and preparing the skin and attaching electrodes for EMG data collection
4. Performing MVIC (maximum voluntary contraction) test
5. Placing and calibrating electrogoniometer on participants
6. Familiarizing participant with testing equipments and protocols
7. Practicing the incline and decline push-up with various cadences
Phase three: performance testing phase (60 minutes)
1. Performing push-ups with a body angle of 45 degree (three sets of three repetitions, each set with a cadence of 20, 30, and 60 beats/minute)
2. Resting for three to five minutes

Table 3.2 (cont'd)
3. Performing push-ups with a body angle of 30 degree (three sets of three repetitions, each set with a cadence of 20, 30, and 60 beats/minute)
4. Resting for three to five minutes
5. Performing push-ups with a body angle of 15 degree* (three sets of three repetitions, each set with a cadence of 20, 30, and 60 beats/minute)
6. Resting for three to five minutes
7. Performing push-ups with a body angle of 0 degree (three sets of three repetitions, each set with a cadence of 20, 30, and 60 beats/minute)
8. Resting for three to five minutes
9. Performing push-ups with a body angle of -10 degree (three sets of three repetitions, each set with a cadence of 20, 30, and 60 beats/minute) * Notes that this is the standard push-up position in which the contact of the hands and feet form a horizontal.

Phase one: participant information and preparation phase

In phase one and step one, the current investigator briefly explained about the purpose of the study, the specific testing procedures, and safety issues. Participants were free to ask any questions or indicate any concerns. After this step, the current investigator went through the consent form (see Appendix A) with the participants, making sure their benefits and protection were clearly understood. Then, signed consent forms were collected. In addition to consent forms, participants also filled out questionnaires (see Appendix C). The questionnaires included participants' medical condition, current health status, training and injury history, and activities within most recent 48 hours. The information would help the investigator further and better understand the performance of the participants so that the experimental results could be more validly explained.

After paperwork was done, anthropometric measurements were conducted by the current investigator. Participants' body weight, standing height, sitting height, arm length, forearm length, hand length, wrist width, elbow width, and bi-acromion breadth were measured in the indicated order. The investigator learned anthropometric techniques in Exercise Physiology courses in Beijing University of Physical Education, had anthropometric measurement experience in various projects as an undergraduate. In MSU, the investigator took KIN811 and KIN830 courses and practiced anthropometric measurements; in project "A dynamic analysis of walking gait between young and senior people" (PI: Dr. Tamara Reid-bush), the investigator got training from another doctoral student Samuel Leitkam and performed anthropometric measurements independently in the project. In Dr. Adam Bruenger's dissertation research, the investigator helped with jumping height measurement. Prior to the current research, the investigator got training from Emily Hill in Kinesiology department and practiced in Dr. Eisenmann's anthropometric class prior to the measurement. To access the reliability of the investigator, five friends were found and volunteered in the practicing anthropometric measurement prior to the experiment. The investigator measured 3 times for each one in a random order, and checked the data for test-retest correlations. Test-retest correlation coefficients with participants' measurement values were attached in the Appendix B. The same investigator conducted all anthropometric measurements for participants.

Phase two: familiarization phase

Phase two began with warming up and stretching. Each participant performed one minute warm up of jumping jacks, followed by appointed six types of stretching. Each type of stretching lasted approximately 30 seconds for each side of the body, except for the wrist and pectoralis major stretch, which were performed only once with both sides' muscles stretched at the same time (Shepard, 2004). Details for how to perform each type of stretching were described as follows:

1. Pectoralis stretch: The participant stood erect, with upper extremities hyper extended as much as possible at the shoulder joint behind the body. The stretching lasted 30 seconds and the participant should feel the pectoralis muscle being stretched to a point of slight discomfort. The target muscles in this stretching are pectoralis major and minor.

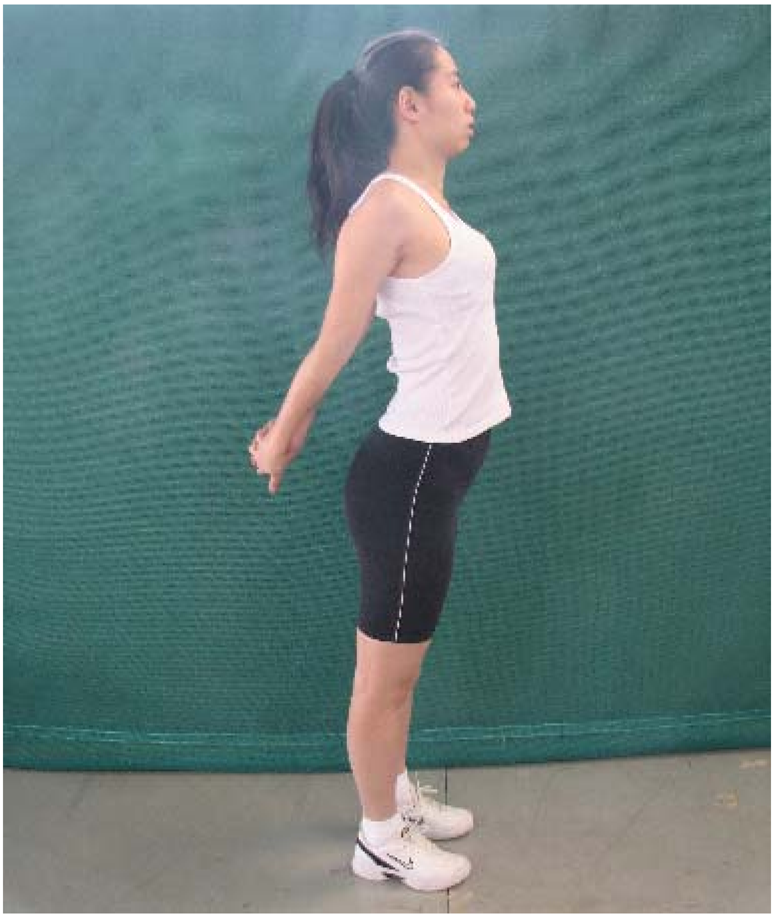

Figure 3.17 Pectoralis major stretch

2. Triceps stretch: In triceps stretching, the participant stood with the body erect and feet shoulder-width apart. The participant abducted one upper extremity at the shoulder joint while flexing the elbow joint, then grabbed the elbow with the opposite hand, and pulled it toward the middle line of the body with light pressure to a point of slight discomfort.

Figure 3.18 Triceps brachii stretch

3. Deltoid stretch: In the deltoid stretching, the participant stood erect with feet shoulder-width apart, horizontally flexing one extremity across the chest and placing the opposite hand on the elbow joint to apply pressure. If the stretching was executed correctly, the participant should feel tension to a point of slight discomfort in the lateral side of the arm.

Figure 3.19 Deltoid stretch

4. Trapezius stretch: The trapezius is a large muscle which is usually divided into upper, middle, and lower parts. In this stretch, the participant held a standing position. The elbow joint that is on the same side of the stretched muscles flexed slightly, so that the forearm and hand were behind the trunk, and the hand on the other side applied slight pressure on the head to help stretch the trapezius without lifting the shoulder on the stretched side. All three parts of the trapezius should feel tension to a point of slight discomfort.

Figure 3.20 Upper trapezius stretch

5. Standing calf stretch: In a staggered stance, the participant stood with the soles of both feet flat on the ground. One lower extremity extended in a straight line behind the trunk, and the other lower extremity should be out in front of the trunk with a flexion of about 30 degrees at the knee joint. The upper body should lean slightly forward with both hands pushing against a wall for support. The hips should be more forward to cause a stretch in the muscles of the calf to a point of slight discomfort (Bruenger, 2008).

Figure 3.21 Standing calf stretch

6. Front wrist stretch: The participant interlaced the fingers and attempted to extend the elbow joints out in front of the trunk. The upper extremities should be parallel to the floor. Pressure should be gently applied to the wrist joint so that the palms and wrists can feel tension to a point of slight discomfort.

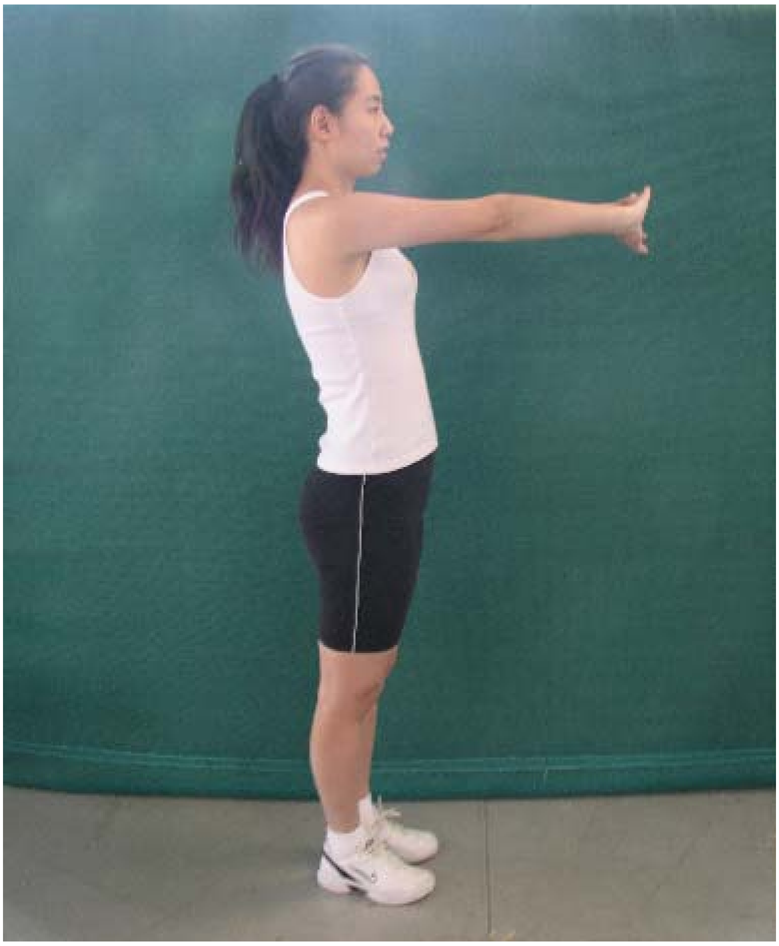

Figure 3.22 Front wrist stretch

After warming up and stretching, participants had the EMG electrodes applied to the selected muscles after the skin was shaved, abraded and cleansed. The specific procedures were described in the *Instrumentation section* of this chapter.

In the familiarization step, the participant performed several trials of push-ups to see if there was any adjustment needed. Many of the participants needed instructions from the investigator about the hand orientation, distance between hands, and body alignment. In addition, this step provided a very important opportunity to the participant to follow the metronome and control the performance pace.

In the step of practicing the incline and decline push-up, the participant was free to try the push-up with any one of the five body angles and three cadences. During the performance, the investigator recorded the data of the trials to check if all the instrumentation was working properly.

Phase three: performance testing phase

Since there were five body angels and three cadences, the goal was to have each participant perform 15 sets. Considering three repetitions for each set, an amount of 45 push-ups was the desired number of push-ups to complete the entire experiment (see Table 3.2). In order to prevent fatigue and improve the validity of the experiment, the testing procedure was divided into five parts. In every part, one angle was tested; the participant performed three sets (nine repetitions) of this angle at three cadences with a 30 seconds break between sets. Each participant began with the easiest angle and performed the hardest one last, considering muscles may have time to gradually get used to the intensity. However, the fixed order may induce biased data, causing some limitations for the study. After each part, three to five minutes of rest occurred. The reason for why participants had different resting cycles (three to five minutes) was because some participants had relatively less muscle strength and needed a longer resting cycle to complete the entire testing. Females in this research needed an average of four and half minutes while males needed an average of three minutes to recover.

Specific details of performance

With electrodes and electrogoniometer attached on the right side of the body, each participant started with the right hand on a force platform which was attached to the surface of the performance board. The orientation system drawn on the force platform was used to guide the participant with respect to the orientation of the hands: middle finger rotated 30 degrees externally and the distance between the third metatarsals of two middle fingers was equal to the bi-acromion breadth.

During the performance, the investigators reminded the participant to “keep hips down and the trunk and lower extremities straight”, as well as “keep the trunk in a neutral position”. A neutral position is one in which the body weight is evenly distributed on both hands. Participants was also instructed to “not fully extend (lock) the elbow joint” when they reached the end of the concentric phase. The metronome gave out three cadences and participants were expected to reach the end of the eccentric and concentric phase at every beat.

Data Analysis

To perform the data analysis, a reference used to tell the events during the push-up motion must be determined first. Both the time sequence and the elbow joint angle were used to tell the events. Time points (e.g., the 3.12 second, when the eccentric phase ended) of the important events of the push-up (start of the eccentric phase, start of the concentric phase) were identified using the elbow joint angle wave. The eccentric phase was the time between the start of the push-up and the attainment of the lowest position and the concentric phase was the time between the start of the ascent and the attainment of the original starting position. The start of the eccentric phase could be identified when the elbow joint angle began to increase (i.e., the elbow joint began to flex). The start of the concentric phase could be identified when the elbow joint angle began to decrease (i.e., the elbow joint began to extend). Once the start point of the eccentric phase and the end point of the concentric phase were determined, a complete push-up cycle (repetition) could be identified. By drawing a graph of the elbow joint angle, hand forces and EMG values on a time axis, the second repetition out of the three push-ups was identified, and all forces and EMG data were cut out within the time period of this repetition. These data were called an “effective data piece” in this study, and it was the basis for the later data analysis.

Force platform data

Three orthogonal forces Fx (anterior-posterior), Fy (medial-lateral), and Fz (perpendicular) were recorded as three waves by the force platform during the incline and decline push-up. In each repetition of the push-up, these three forces reached the maximum at the end of the eccentric phase and the start of the concentric phase, or, a turning point of the two phases. In an effective data piece, these maximum Fx, Fy, and Fz were found by the second investigator, and then normalized to the participant’s body weight. The value obtained from this method was a percent of body weight, and was drawn as a dependant variable of the body angle on graphs to explore if there was a linear relationship between them. In addition, the pattern of the Fz was determined for the incline and decline push-up at cadence 2 and compared between these two variants. Further, a repeated measures ANOVA was used as a statistical method to investigate the effects of the cadence on these maximum forces.

EMG data

The EMG data were filtered using a 10 Hz high pass Butterworth filter and then full wave rectified. Because full wave rectification contains the entire EMG signal, it is usually the preferred method of modification. The modifying course consisted of the negative signal being converted to positive value.

In this study the electromyographic (EMG) data were full wave rectified, integrated and then normalized with respect to Maximum Voluntary Isometric Contraction (MVIC) test for respective muscles over the same time intervals. Specifically, the EMG signals for the second complete push-up cycle were cut out of the three cycles, full wave rectified, and integrated by an Excel program to get a value V1. The EMG value from the MVIC test (six seconds) was also cut out to get a data piece within a period of two to three seconds. This data piece was then full wave rectified, integrated by an Excel program, and then divided by the time to get a unit value. This unit value timed the duration of the second push-up cycle (e.g., 4s) and then a value V2 was attained. Finally, V1 was divided by V2, a percentage of muscle activity of the second repetition (eccentric and concentric phases) to MVIC test was obtained and this is called a normalization. Normalized EMG values were compared across workout conditions using ANOVAs with repeated measures. An alpha level of 0.05 was the criteria for statistical significance in all cases.

Data Management

All kinetic, kinematic and electromyography (EMG) data were stored on a secure laboratory computer. Every participant was coded into a number and all files were under coded names. The current investigator and dissertation committee members are the only individuals with the access key to link these codes to the participants. The keys that match the participants' data are stored in a locked file cabinet. Once the dissertation is completed, the keys will be destroyed.

CHAPTER 4: RESULTS

CHAPTER 4 includes the characteristics of the participants and the research results which are corresponding to the eight research questions.

The purpose of the first and second research question is to investigate if there is a relationship between the maximum hand forces, represented as a percentage of body weight, and the incline and decline push-up angle. The main focus of the third research question is to take a close look at the relatively most active muscle during a standard push-up. The fourth research question evaluates if the pattern of activation of the selected muscles is different in the incline and decline push-up. The aim of fifth research questions is to explore the effects of different cadences on the maximum hand forces. The sixth research question investigates the pattern of the perpendicular force Fz during the incline and decline push-up at cadence 2. The seventh and eighth questions explore the effects of the cadence and incline and decline angle on the muscles' activation levels.

The raw research data were processed in eight steps: 1. changing all data files into Excel format; 2. adding time sequence to each data sheet; 3. cutting out data of the second repetition out of three push-up repetitions; 4. finding out the maximum values for the three forces Fx, Fy, and Fz; 5. conducting integration of full-wave rectified EMG data; 6. normalizing force values using body weight; 7. normalizing EMG data using MVIC test; 8. running statistical analysis (Pearson correlation, repeated measures MANOVA, and Boferroni comparisons).

In step 8 when running statistical analysis, two female participants had outliers in pectoralis major EMG value which were relatively higher than others. These two outliers were removed prior to running the repeated measures ANOVA considering the number of outliers was small (Bruenger, 2008). EMG values were evaluated for normality and no excessive kurtosis or skewness (kurtosis or skewness score/standard error > 3.0) was found.

One of the assumptions about the gender difference was tested in this dissertation with two-group T-test. Results showed that no significant differences were seen on three forces and four EMG values versus gender, proving that the gender assumption was held in this study.

Participants' Characteristics

Table 4.1 presents the characteristics of the participants. Twenty-eight adults volunteered for this study. The first four were participating only in the pilot study, so in the current study the data from 24 of the participants were analyzed. Among the 24 participants, there were 18 males and six females. These 24 participants consisted of college freshmen to senior year students and some recreational weight trainers from off campus fitness centers. Eight of the participants were weight training and conditioning, the others were not. But, all participants had at lease six month experience of doing push-ups. All were currently free from injuries that could adversely affect their performances of the push-up. The age of the participants ranged from 18 to 23 years.

Table 4.1

Characteristics of Participants (N=24)

	Entire Population (N = 24)	**Males (N=18)**	**Females (N=6)**
Characteristics	**Mean±SD**	**Mean±SD**	**Mean±SD**
Ages (yrs)	19.8±1.4	19.3±1.1	21.3±1.6
Weight (lbs)	159.8±26.7	166.4±24.8	140.0±29.4
Height (cm)	173.9±9.5	179.2±10.3	158.0±9.7
Sitting Height (cm)	93.9±4.8	98.6±6.6	79.8±3.2
Hand Length(cm)	19.1±1.2	19.9±1.8	16.7±1.0
Forearm Length (cm)	26.5±1.8	28.8±1.7	19.6±1.6
Arm Length (cm)	29.8±2.7	32.0±2.5	23.2±2.8
Wrist Width (cm)	6.3±0.4	6.5±0.2	5.7±0.6
Elbow Width (cm)	9.4±0.8	9.8±1.0	8.2±0.9
Bi-acromion Breadth (in.)	17.6±1.5	19.0±1.3	13.4±1.8

Research Questions

RQ1.*For the incline push-up, is there a relationship between the maximum hand forces, as a percentage of body weight, and incline angle? When the incline angle increases, will the maximum hand forces decrease?*

As stated in the Data Analysis section of CHAPTER 3, for the second push-up in the repetition of three push-ups of each trial, the three forces (Fx, Fy, and Fz) reached their maximum at the end of the eccentric phase and the start of the concentric phase, or, at the turning point (point #5 in research question six) of the two phases. These maximum forces were then normalized to the body weight of each participant, so they were represented as a percentage of body weight after the normalization was done. In this research question, mean maximum hand forces as a percentage of the body weight for the 24 participants were drawn in Figures 4.1-4.3 as the y axis, and the corresponding body angles (≅15, 30, 45 degrees) were drawn as the x axis. To make the changes of the forces more clear, the body angle of approximate 15 degrees, which corresponded to the standard push-up, was set as the starting point for the lines in Figures 4.1-4.3. In Tables 4.2-4.4, the Pearson correlation coefficients were calculated for Fx, Fy, and Fz, respectively. These correlations were determined by using body angles of ≅15, 30, 45 degrees and the corresponding forces in percentages of body weight. “The inclines angle increases” means the body angle increases from ≅15 to 30 to 45 degrees.

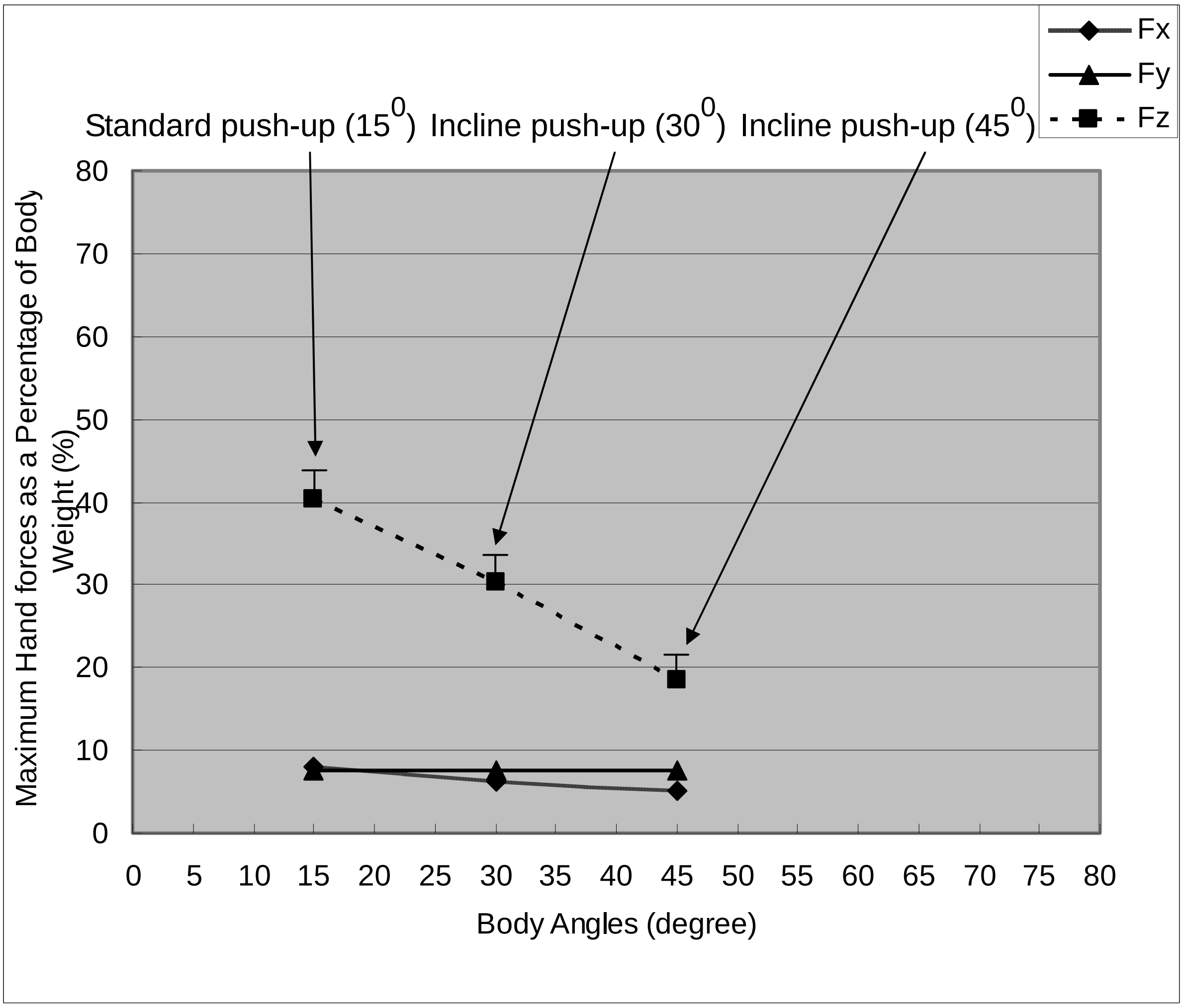

Figure 4.1 Relationships between body angles and mean maximum hand forces (Fx, Fy, and Fz) in incline push-up for cadence 1 (20 beats/minute)

Table 4.2

Pearson Correlations between the Incline Angle and Mean Maximum Hand Forces for Cadence 1

Variables	**Incline Angle versus Fx**	**Incline Angle versus Fy**	**Incline Angle versus Fz**
Correlation Coefficient	-0.988	0.000	-1.000

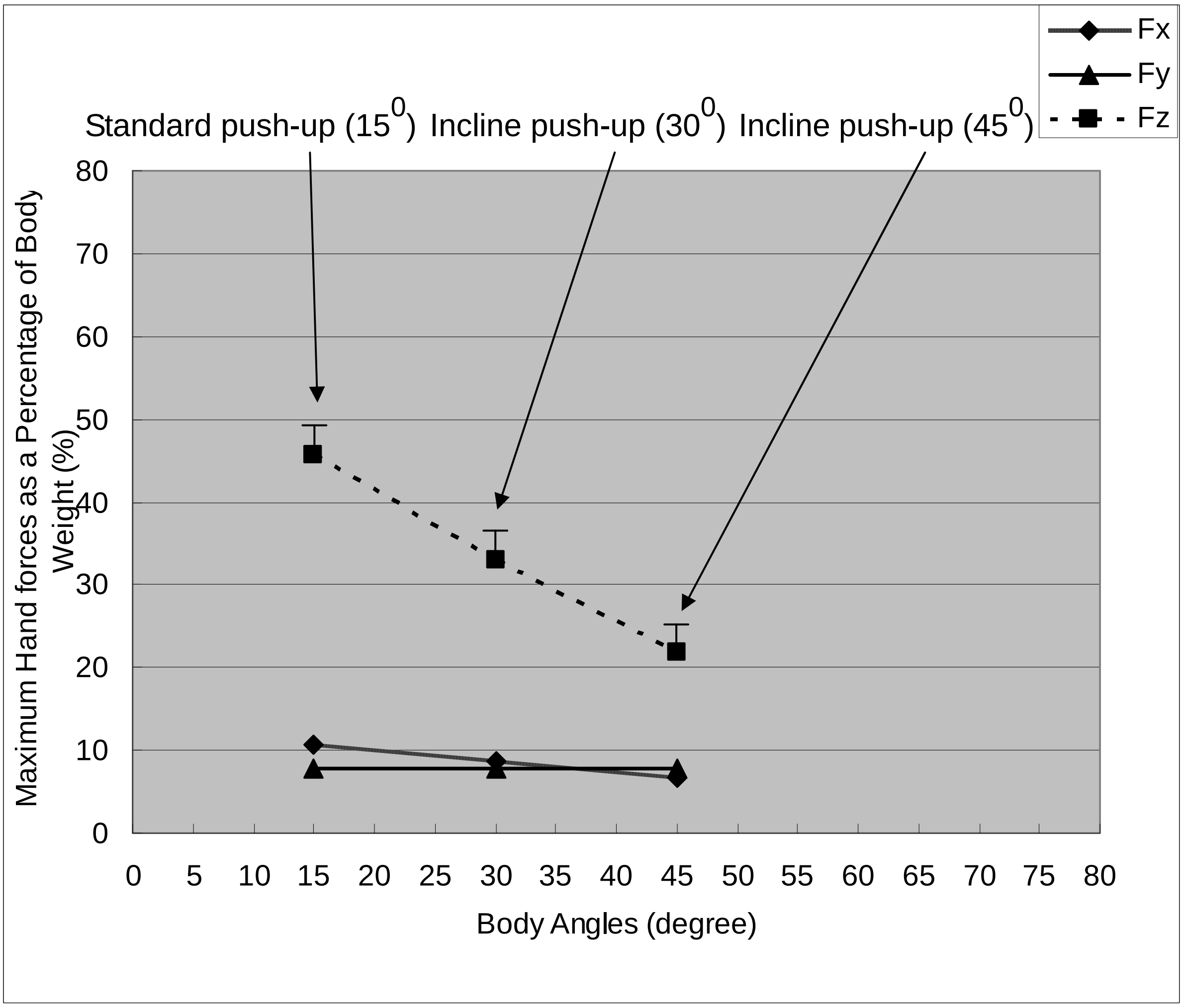

Figure 4.2 Relationships between body angles and mean maximum hand forces (Fx, Fy, and Fz) in incline push-up for cadence 2 (30 beats/minute)

Table 4.3

Pearson Correlations between the Incline Angle and Mean Maximum Hand Forces for Cadence 2

Variables	**Incline Angle versus Fx**	**Incline Angle versus Fy**	**Incline Angle versus Fz**
Correlation Coefficient	-0.988	-0.500	-1.000

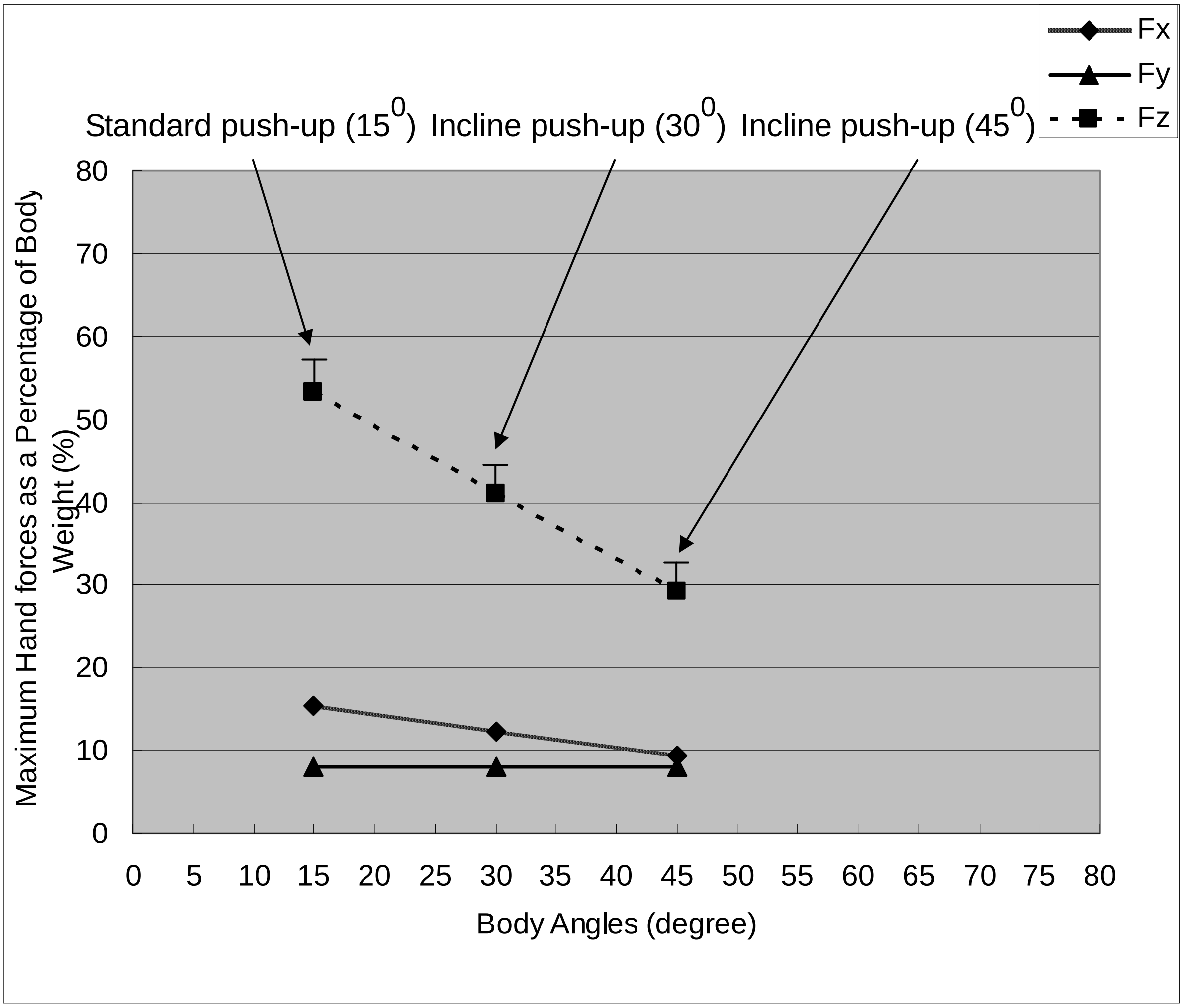

Figure 4.3 Relationships between body angles and mean maximum hand forces (Fx, Fy, and Fz) in incline push-up for cadence 3 (60 beats/minute)

Table 4.4

Pearson Correlations between the Incline Angle and Mean Maximum Hand Forces for Cadence 3

Variables	**Incline Angle versus Fx**	**Incline Angle versus Fy**	**Incline Angle versus Fz**
Correlation Coefficient	-0.988	-0.866	-0.999

In all three cadences, there was an obvious relationship between the incline angle and two mean maximum hand forces (Fx and Fz). When the incline angle increased from ≅15 to 30 to 45 degrees, the forces decreased correspondingly. The correlation coefficient was very close to -1 for Fx and Fz, proving that there was an near perfect linear relationship between the incline angles and the two mean maximum hand forces. The negative value of the correlation coefficients indicated that the trend of the forces was opposite to the body angles. There was no obvious relationship between the incline angle and the mean maximum medial-lateral force Fy in cadence 1, because the Pearson correlation coefficient was 0; however, the Pearson correlation increased to -0.500 in cadence 2 and to -0.866 in cadence 3. It is likely that an increase in cadence could induce a more obvious relationship between the incline angle and the mean maximum hand Fy.

RQ2.*For the decline push-up, is there a relationship between the maximum hand forces, as a percentage of body weight, and decline angle? When the decline angle increases, will the maximum hand forces increase?*

As stated in the Data Analysis section of CHAPTER 3, for the second push-up in the repetition of three push-ups of each trial, the three forces (Fx, Fy and Fz) reached their maximum at the end of the eccentric phase and the start of the concentric phase, or, at the turning point (point #5 in research question six) of the two phases. These maximum forces were then normalized to the body weight of each participant, so they were represented as a percentage body weight after the normalization was done. In this research question, mean maximum hand forces as a percentage of body weight for the 24 participants were drawn in Figures 4.4-4.6 as the y axis, and the corresponding body angles (≅15, 0, -10 degrees) were drawn as the x axis. To make the changes of the forces more clear, the body angle of approximate 15 degrees, which corresponded to the standard push-up, was set as the starting point for the lines in Figures 4.4-4.6. In Tables 4.5-4.7, the Pearson correlation coefficients were calculated for Fx, Fy, and Fz, respectively. These correlations were determined by using body angles of ≅15, 0, -10 degrees and the corresponding forces in percentages of body weight. “The declines angle increases” means the body angle decreases from ≅15 to 0 to -10 degrees in this question.

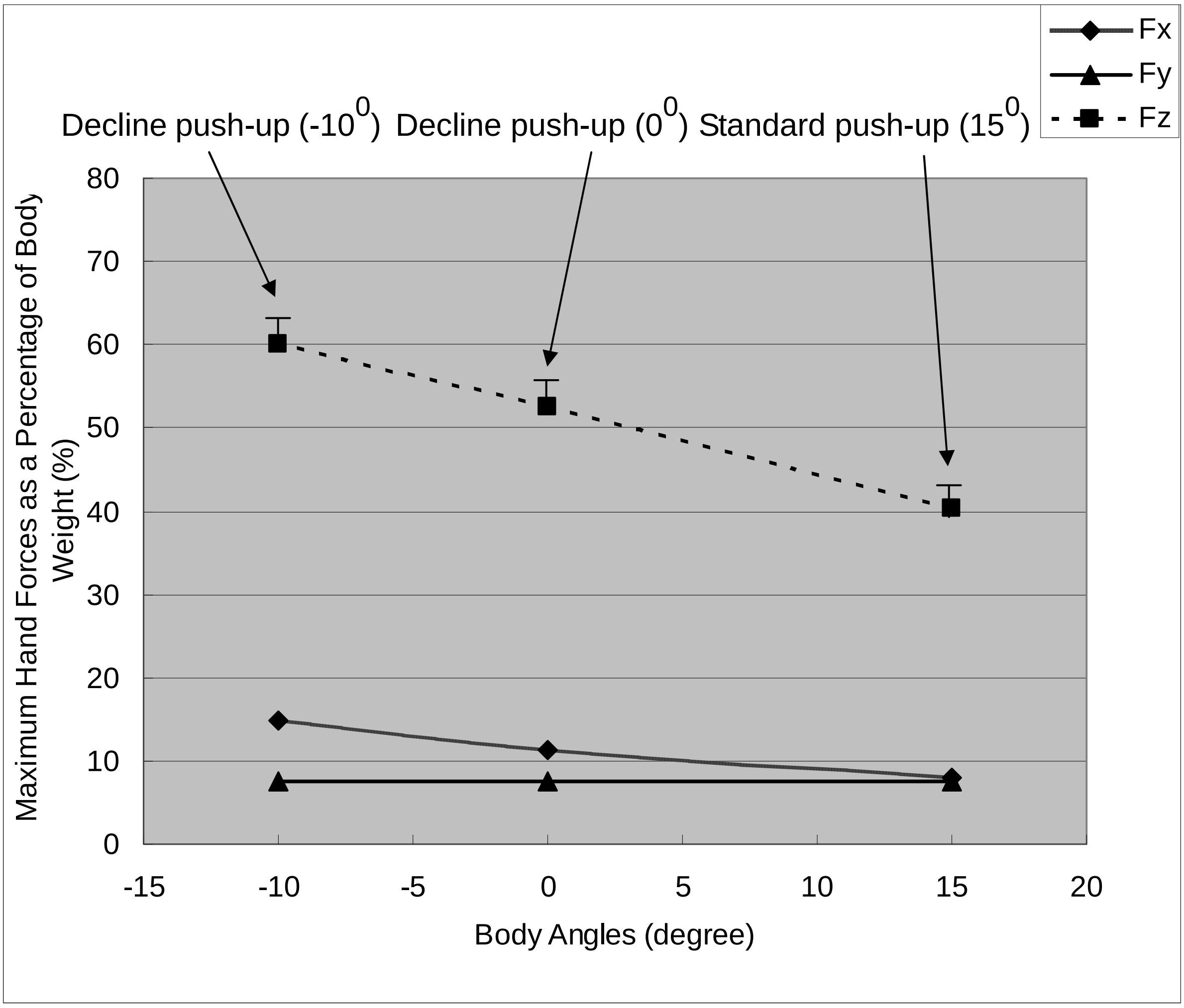

Figure 4.4 Relationships between body angles and mean maximum hand forces (Fx, Fy, and Fz) in decline push-up for cadence 1 (20 beats/minute)

Table 4.5

Pearson Correlations between the Decline Angle and Mean Maximum Hand Forces for Cadence 1

Variables	**Decline Angle versus Fx**	**Decline Angle versus Fy**	**Decline Angle versus Fz**
Correlation Coefficient	-0.995	+0.397	-0.999

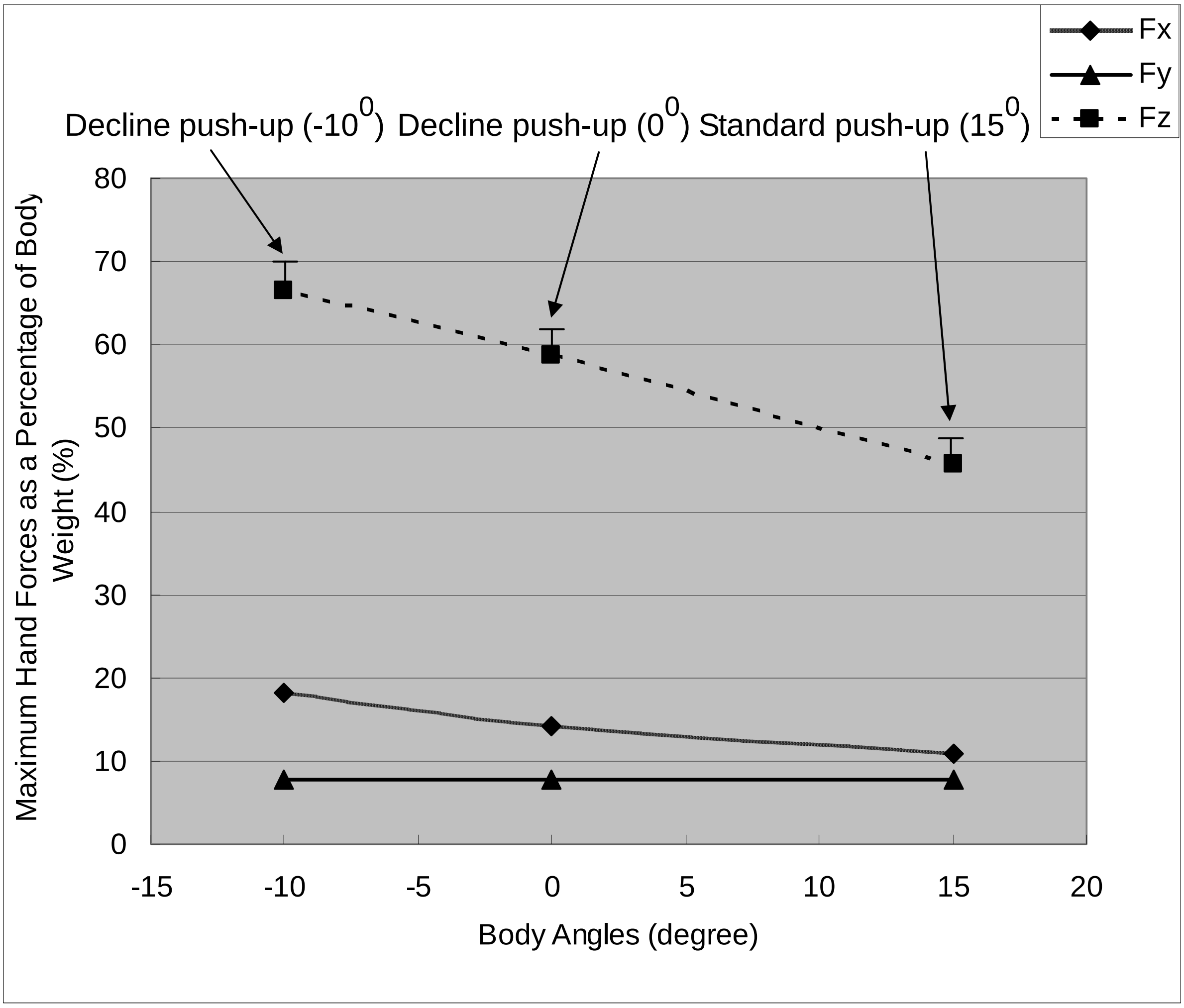

Figure 4.5 Relationships between body angles and mean maximum hand forces (Fx, Fy, and Fz) in decline push-up for cadence 2 (30 beats/minute)

Table 4.6

Pearson Correlations between the Decline Angle and Mean Maximum Hand Forces for Cadence 2

Variables	**Decline Angle versus Fx**	**Decline Angle versus Fy**	**Decline Angle versus Fz**
Correlation Coefficient	-1.000	-0.115	-0.999

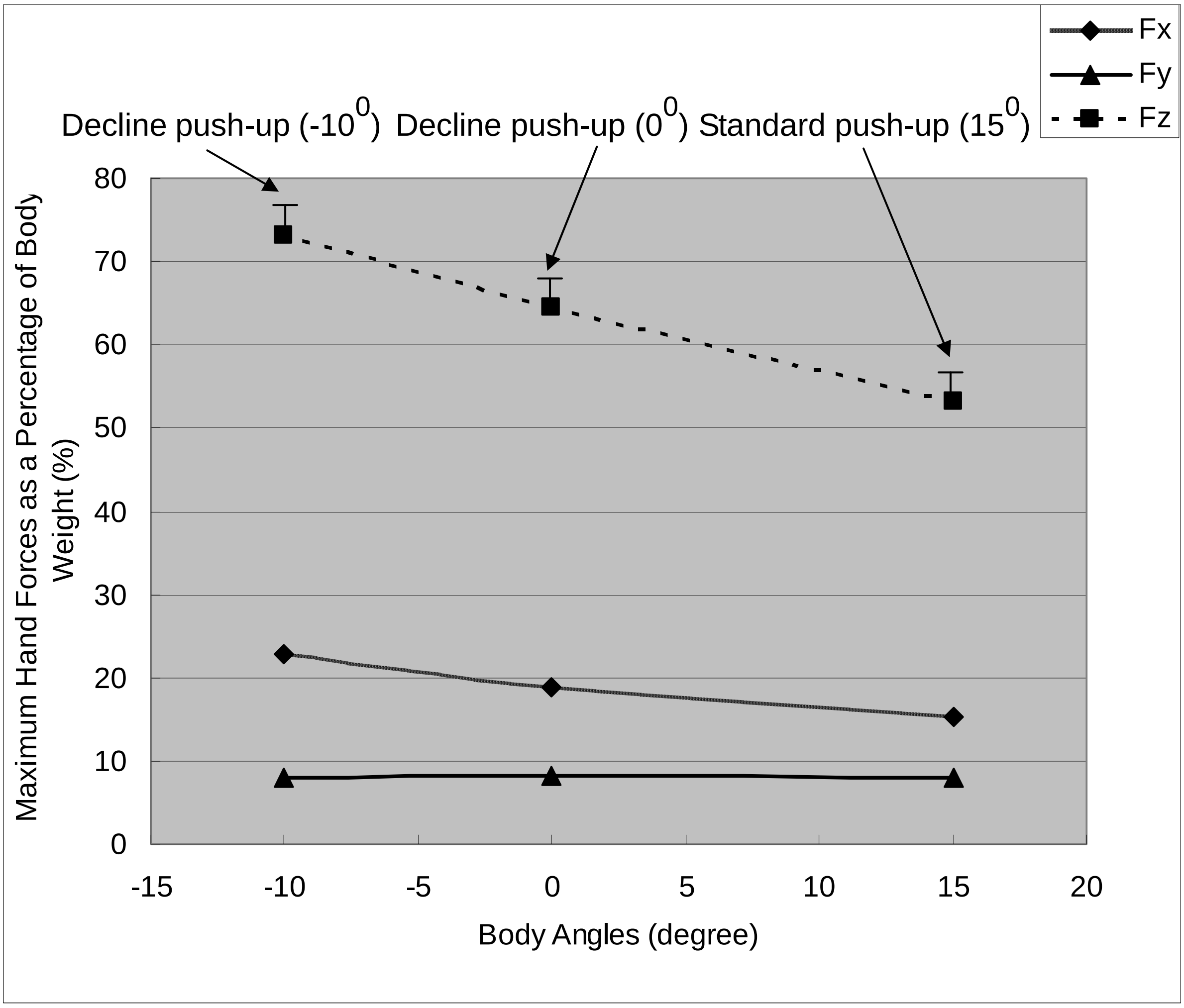

Figure 4.6 Relationships between body angles and mean maximum hand forces (Fx, Fy, and Fz) in decline push-up for cadence 3 (60 beats/minute)

Table 4.7

Pearson Correlations between the Decline Angle and Mean Maximum Hand Forces for Cadence 3

Variables	**Decline Angle versus Fx**	**Decline Angle versus Fy**	**Decline Angle versus Fz**
Correlation Coefficient	-1.000	-0.115	-1.000

In all three cadences, there were obvious relationships between the decline angle and two mean maximum hand forces Fx and Fz. When the decline angle increased (from +≅15 to 0 to -10 degree), the forces increased correspondingly. The correlation coefficient was very close to -1 for Fx and Fz, proving that there was an near perfect linear relationship between the decline angles and the two mean maximum hand forces. The negative value of correlation coefficients indicated that the trend of the forces was opposite to the body angles. For the mean maximum medial-lateral force Fz, the Pearson correlation coefficients were +0.397, -0.115, and -0.115 for the three cadences, respectively. The results indicated no obvious relationship between these two variables.

RQ3*. Which muscle among pectoralis major, triceps brachii, deltoid, and upper trapezius is relatively most active in comparison to its recorded Maximum Voluntary Isometric Contraction (MVIC) during the typical standard push-up with cadence 2 (30 beats/minute)?*

The second investigator integrated each of the full-wave rectified EMG signals over the entire cycle of the second push-up in the repetition of three push-ups of each trial and then divided by a time interval of two to six seconds (two for push-up with cadence 3, four for push-up with cadence 2, and six for push-up with cadence 1) and then compared this value to the full-wave rectified and integrated EMG signal for the same muscle in the MVIC test for the same time period. Mean muscle activity as a percentage of MVIC test for the 24 participants were then obtained for each muscle. “Relatively most active” muscle in this question means the muscle with the highest percentage value of activation relative to the normalized MVIC test for the same time interval. Figure 4.7 showed the muscle activation levels of the four muscles in a typical standard push-up with cadence 2. The reason for selecting the standard push-up with cadence 2 is because this is the push-up that is most often used by weigh trainers and exercise programs.

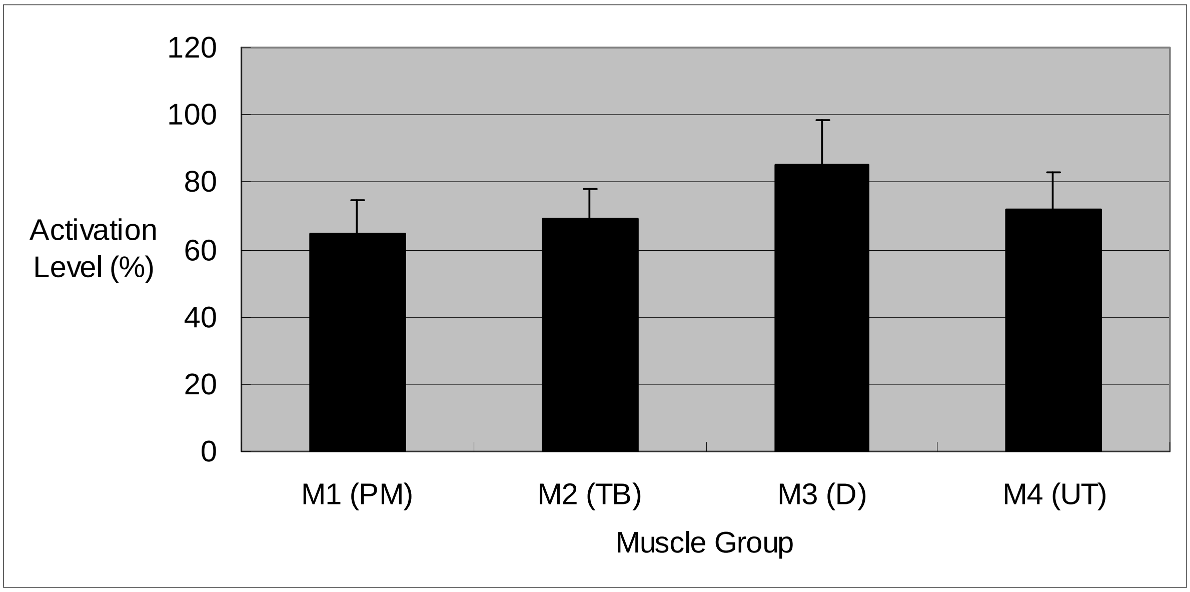

Figure 4.7 Full-wave rectified and integrated muscle activation level in a standard push-up with cadence 2 (30 beats/minute) in comparison to Maximum Voluntary Isometric Contraction (MVIC) test of the same muscle normalized for the same time interval

M1(PM) = Pectoralis Major; M2 (TB) = Triceps Brachii;

M3 (D) = Deltoid; M4 (UT) = Upper Trapezius.

Through comparison of the activation levels of the four muscles, the relatively most active muscle during a typical standard push-up with cadence 2 was deltoid (85.3%), followed in order by the upper trapezius (72.1%), triceps brachii(68.9%), and pectoralis major(64.5%). Figure 4.7 illustrated the mean percentage values of each of the four muscles during the standard push-up with cadence 2 (two seconds for eccentric phase and two seconds for concentric phase). These results will be discussed further in research question 3 of CHAPTER 5.

RQ4. *Will the recruitment pattern of selected muscles (pectoralis major, triceps brachii, deltoid, and upper trapezius) be different in the incline and decline push-up at cadence 2 (30 beats/minute)?*

Only one participant was used for this research question as a typical example of all other participants, because the muscle recruitment patterns of this participant were very similar to that of others. The EMG data from three push-up repetitions of each trial were used. To compare the recruitment patterns of the four selected muscles, typical EMG signal examples were selected from a participant performing push-ups at -10 degrees (decline push-up) and 45 degrees (incline push-up), because these two body angles were extremities. EMG examples were extracted at cadence 2 (30 beats/minute). Figure 4.8 illustrated the visual comparison of the muscle activity patterns. The start point of the eccentric phase, the end point of the eccentric phase and start point of the concentric phase, and the end point of the concentric phase were indicated in Figure 4.8 by three vertical lines.

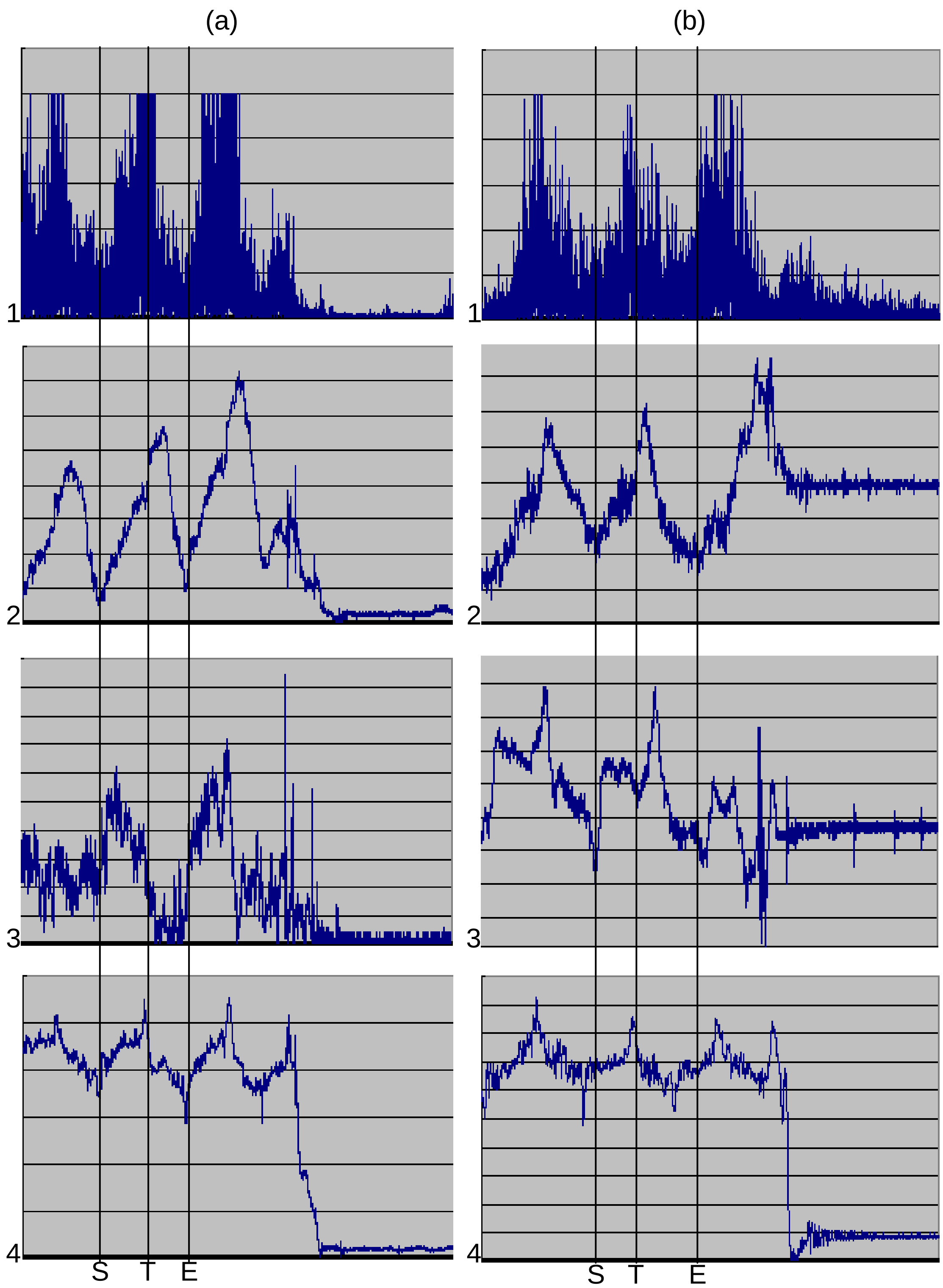

Figure 4.8 Typical full-wave rectified EMG pattern for three repetitions of (a) incline push-up of 45 degrees body angle and (b) decline push-up of -10 degrees body angle performed at cadence 2

1 = Deltoid; 2 = Upper Trapezius; 3 = Pectoralis Major; 4 = Triceps Brachii;

S = Start of the eccentric phase (elbow angle = 0^0); T = End of the eccentric phase and start of the concentric phase (elbow angle = 90^0); E = End of the concentric phase (elbow angle = 0^0)

.

From comparison of the recruitment patterns of the four selected muscles, only the recruitment pattern of the deltoid and triceps brachii changed during the incline and decline push-up, with deltoid muscle exerting more and triceps brachii muscle having a burst of strength during the eccentric phase in the decline push-up.

RQ5*.Will different performance cadences change the maximum hand forces (Fx, Fy, and Fz), as a percentage of body weight, that occur during the incline, standard, and decline push-ups?*

The three maximum hand forces from the second push-up in three push-up repetitions of each trial for all 24 participants were used for this research question. Here the decline push included two angles: 0 and -10 degrees. The maximum hand forces for these two angles were averaged first and then used in the statistical analysis in all three cadences. The maximum hand forces for the incline push-up were processed in the same way.

The basic method of performing statistical analysis for this question was to conduct ANOVA first to examine if there were any differences between the dependent variables' means. If ANOVA indicated a P value less than 0.05, then Boferroni Comparisons were conducted to find out which two groups had a statistically significant difference. Because this study had several independent variables (body angles and cadences) and dependent variables (forces and EMG signals), each independent variable had more than two levels (e.g., three cadences), and repeated measures were made at different time points with each participant contributing seven scores each time, so a repeated measures Analysis of Variance (ANOVA) was selected.

Two assumptions need to be upheld for conducting a repeated measures ANOVA: the assumption of Normality and Mauchly's Test of Sphecirity. Only under the condition that these two assumptions were met, a repeated measures univariate

ANOVA could be performed. Otherwise, a repeated measures MANOVA was highly recommended. In the situation of a MANOVA indicating a significant difference and one of the two assumptions not being upheld, a subsequent univariate ANOVA could be performed for any two groups with conducting the Greenhouse-Geiser adjustments (Qiu et al., 2006).

In this question, sample statistical analysis of the decline push-up was presented. The force data were statistically analyzed in the following six steps: 1. Force values were first evaluated for normality and for outliers. No excessive kurtosis or skewness (kurtosis or skewness score/standard error > 3.0) and no outliers (z scores < 3.0) were found; 2. Mauchly's Test of Sphecirity was run to check if there was an interaction between repeated measures. The assumption of Sphecirity was upheld for Fy (P = 0.093 > 0.05), but not for Fx (P = 0.000 < 0.005) and Fz (P = 0.001 < 0.05). The results are presented in Tables 4.8; 3. Means and standard deviations for the three forces borne at the right hand are illustrated in Figures 4.9-4.11; 4. A repeated measures ANOVA was performed with an alpha level of 0.05. Tables 4.9-4.10 provided test of between-subjects effects of the maximum hand forces and multivariate tests of the maximum hand forces; 5. Boferroni was performed to determine which of the three cadences resulted in statistically significant values. Table 4.11 provided the results.

Table 4.8

Mauchly's Test of Sphecirity of the Maximum Hand Forces

Fx							
Within Subjects Effect	**Mauchly's W**	**Approx. Chi-Square**	**df**	**Sig**	**Epsilon**		
					Greenhouse-Geisser	**Huynh-Feldt**	**Lower-bound**
Time	0.474	16.433	2	.000	0.655	0.679	0.500
Fy							
Within Subjects Effect	**Mauchly's W**	**Approx. Chi-Square**	**df**	**Sig**	**Epsilon**		
					Greenhouse-Geisser	**Huynh-Feldt**	**Lower-bound**
Time	0.806	4.752	2	0.093	0.837	0.895	0.500
Fz							
Within Subjects Effect	**Mauchly's W**	**Approx. Chi-Square**	**df**	**Sig**	**Epsilon**		
					Greenhouse-Geisser	**Huynh-Feldt**	**Lower-bound**
Time	0.531	13.924	2	0.001	0.681	0.709	0.500

Table 4.9

Test of Between-Subjects Effects of the Maximum Hand Forces

Fx						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	19846.296	1	19846.296	14310.401	.000	.998
Error	31.897	23	1.387			
Fy						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	4455.051	1	4455.051	66008.782	.000	1.000
Error	1.552	23	.067			
Fz						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	274787.556	1	274787.556	5646.600	.000	.996
Error	1119.278	23	48.664			

Table 4.10

Multivariate Tests of the Maximum Hand Forces

Multivariate Tests of Fx						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.970	355.382	2.000	22.000	.000	.970
Multivariate Tests of Fy						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.862	68.675	2.000	22.000	.000	.862
Multivariate Tests of Fz						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.891	90.140	2.000	22.000	.000	.891

Table 4.11

Bonferroni Comparisons for the Maximum Hand Forces

Pairwise Comparisons of Fx						
(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	-3.109*	.159	.000	-3.519	-2.699
	3	-7.548*	.347	.000	-8.444	-6.653
2	1	3.109*	.159	.000	2.699	3.519
	3	-4.439*	.358	.000	-5.365	-3.514
3	1	7.548*	.347	.000	6.653	8.444
	2	4.439*	.358	.000	3.514	5.365
Pairwise Comparisons of Fy						
(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	-.309*	.068	.781	-.486	-.132
	3	-.628*	.054	.773	-.767	-.489
2	1	.309*	.068	.604	.132	.486
	3	-.319*	.081	.612	-.527	-.111
3	1	.628*	.054	.945	.489	.767
	2	.319*	.081	.932	.111	.527
Pairwise Comparisons of Fz						
(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	-4.971*	1.470	.008	-8.766	-1.176
	3	-11.444*	1.207	.000	-14.559	-8.329
2	1	4.971*	1.470	.008	1.176	8.766
	3	-6.473*	.726	.000	-8.348	-4.598
3	1	11.444*	1.207	.000	8.329	14.559
	2	6.473*	.726	.000	4.598	8.348

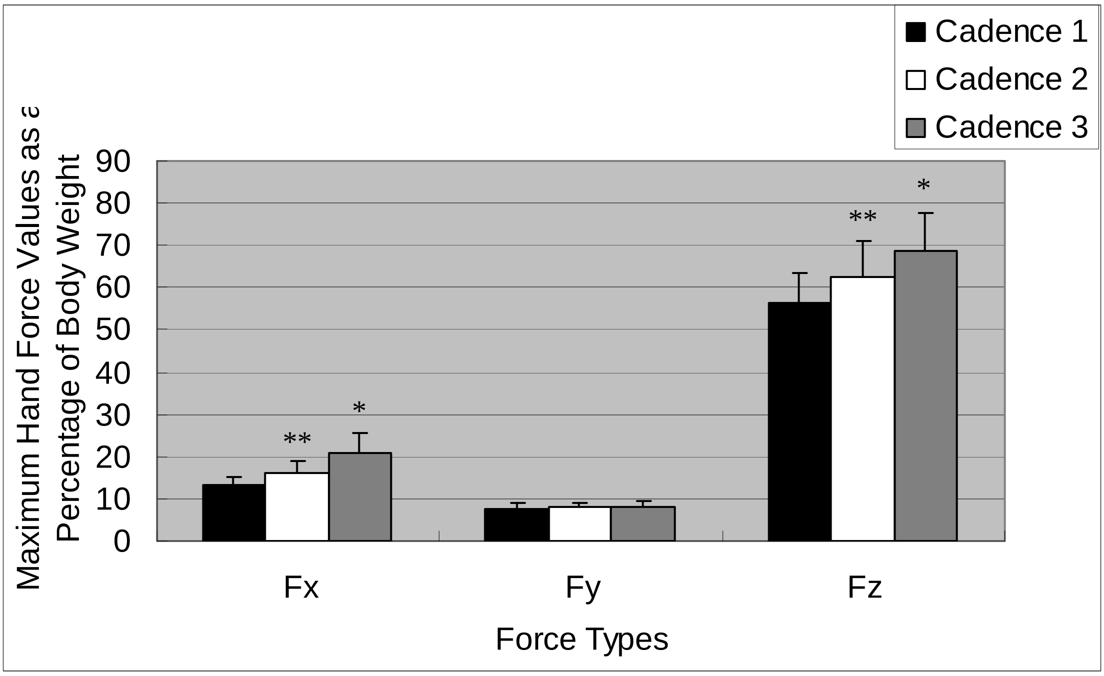

Figure 4.9 Means and standard deviations of the maximum hand forces in the three cadences for the decline push-up

Cadence 1 = 20 beats/min = three seconds for eccentric and eccentric

Cadence 2 = 30 beats/min = two seconds for eccentric and eccentric

Cadence 3 = 60 beats/min = one second for eccentric and eccentric

* = Significantly different than Cadence 1 and Cadence 2

** = Significantly different than Cadence1

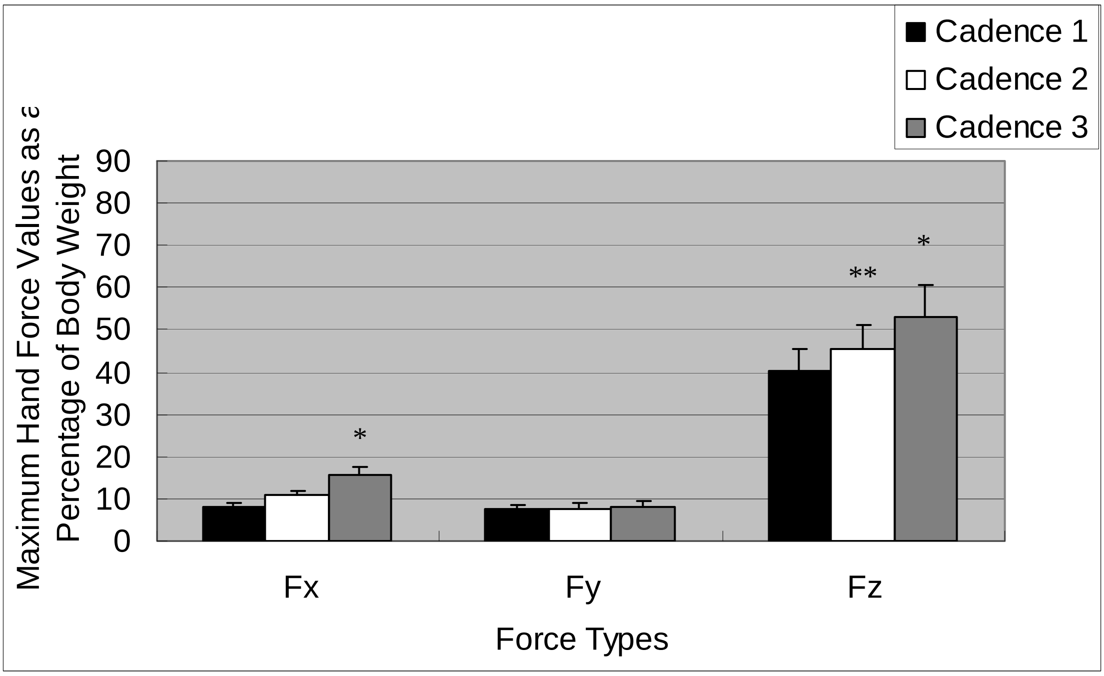

Figure 4.10 Means and standard deviations of the maximum hand forces in the three cadences for the standard push-up

Cadence 1 = 20 beats/min = three seconds for eccentric and eccentric

Cadence 2 = 30 beats/min = two seconds for eccentric and eccentric

Cadence 3 = 60 beats/min = one second for eccentric and eccentric

* = Significantly different than Cadence 1 and Cadence 2

** = Significantly different than Cadence1

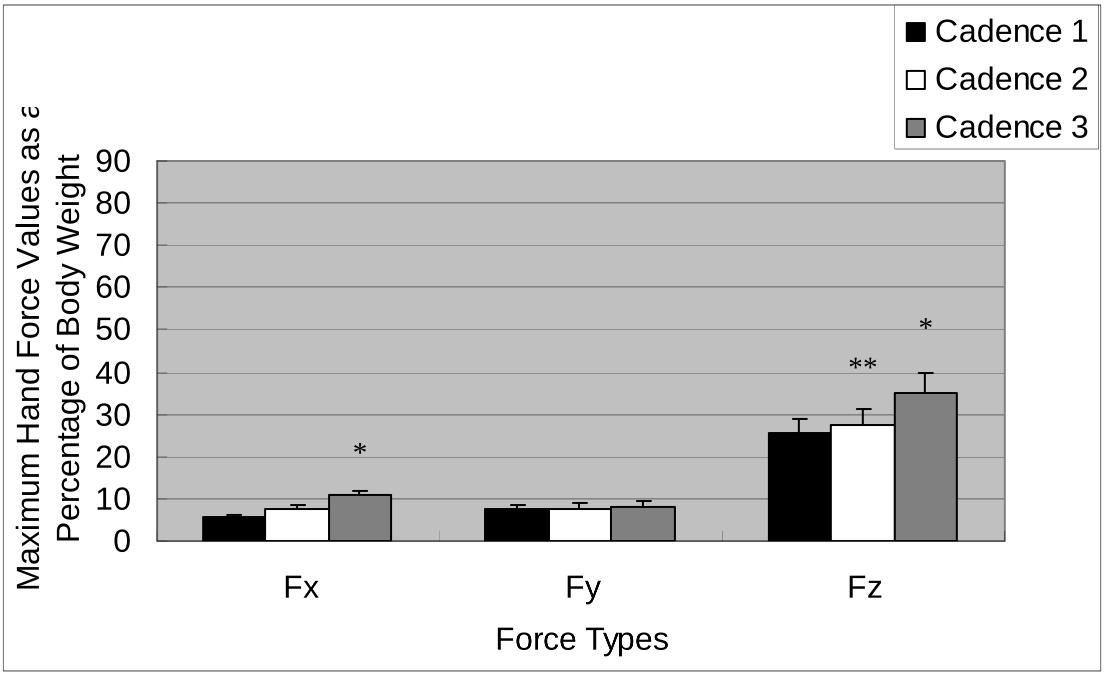

Figure 4.11 Means and standard deviations of the maximum hand forces in the three cadences for the incline push-up

Cadence 1 = 20 beats/min = three seconds for eccentric and eccentric

Cadence 2 = 30 beats/min = two seconds for eccentric and eccentric

Cadence 3 = 60 beats/min = one second for eccentric and eccentric

* = Significantly different than Cadence 1 and Cadence 2

** = Significantly different than Cadence1

For the decline, standard, and incline push-up, maximum perpendicular hand force Fz showed a statistically significant difference when the cadence changed from 1 to 2, 1 to 3, and 2 to 3. Maximum anterior-posterior hand force Fx showed a statistically significant difference when the cadence changed from 1 to 2, 1 to 3, and 2 to 3 in the decline push-up, and a statistically significant difference when the cadence changed from 1 to 3 and 2 to 3 in the standard and incline push-up. Maximum medial-lateral force Fy did not show any statistically significant difference in all three push-ups along the cadence change.

RQ6*.How does the pattern of the maximum perpendicular hand force (Fz) change from the incline push-up to decline push-up?*

Fz values for the first and second push-up in three push-up repetitions of each trial were used in this research question. Two push-ups were selected because the start and end points for the eccentric phase and concentric phase could be seen clearly in this way. To compare the perpendicular force, typical Fz pattern examples were selected from a participant at -10 degrees and 45 degrees body angles, because the Fz pattern from this participant was representative of all other participants and these two push-ups are extremities in body angles used. Fz examples were extracted at cadence 2 to make the comparison effective. Figure 4.12 illustrated the visual comparison of the Fz pattern. The graph was divided into five phases. The maximum Fz appeared at point #5 when the participant began to extend the elbow joint; in other words, when he/she began the concentric phase.

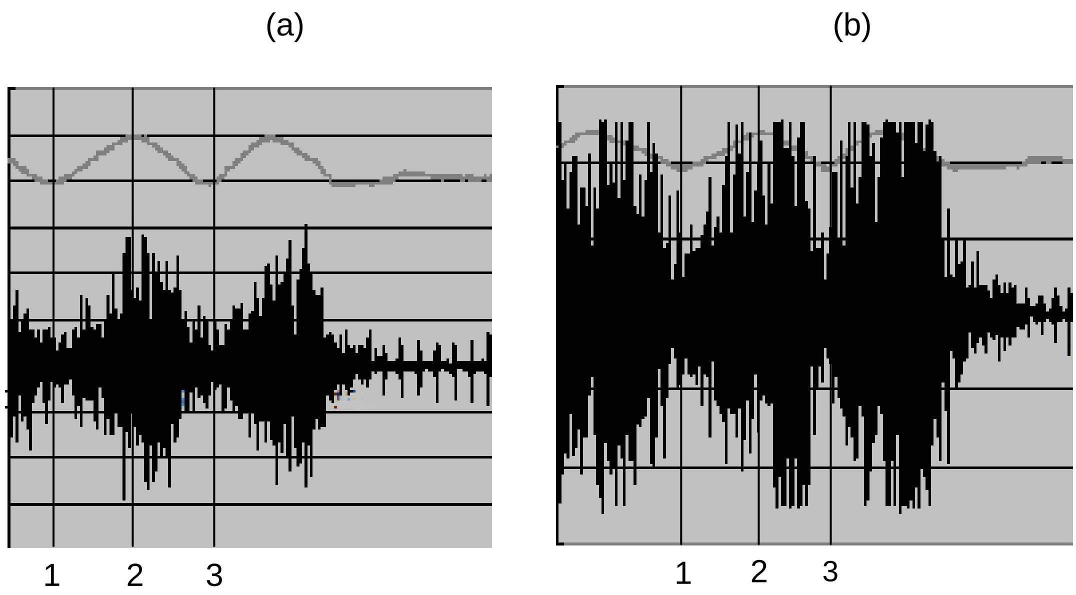

Figure 4.12 Typical perpendicular force Fz pattern for the second repetition of (a) incline push-up of 45 degrees body angle and (b) decline push-up of -10 degrees body angle

1 = Start of the eccentric phase; 2 = End of the eccentric phase and start of the concentric phase; 3 = End of the concentric phase.

The word “pattern” in this research question is defined as the way in which the muscle is activated (e.g., a large Fz magnitude in the eccentric phase corresponding to a strength burst) during the eccentric and concentric phases. The general Fz pattern did not show obvious changes for the incline and decline push-up, only the pattern during the phase between point #1 and #2 indicated a change in magnitude.

RQ7.*How will electromyographic activity of selected muscles differ among the incline, standard, and decline push-ups when normalized to MVIC test?*

The three maximum hand forces from the second push-up in three push-up repetitions of each trial for all 24 participants were used for this research question. Here the decline push included two angles: 0 and -10 degrees. The maximum hand forces for these two angles were averaged first and then used in the statistical analysis in all three cadences. The maximum hand forces for the incline push-up were processed in the same way.

The basic method of performing statistical analysis for this question was to conduct ANOVA first to examine if there were any differences between the dependent variables' means. If ANOVA indicated a P value less than 0.05, then Boferroni Comparisons were conducted to find out which two groups had a statistically significant difference. Because this study had several independent variables (body angles and cadences) and dependent variables (forces and EMG signals), each independent variable had more than two levels (e.g., three cadences), and repeated measures were made at different time points with each participant contributing seven scores each time, so a repeated measures Analysis of Variance (ANOVA) was selected.

Two assumptions need to be upheld for conducting a repeated measures ANOVA: the assumption of Normality and Mauchly's Test of Sphecirity. Only under the condition that these two assumptions were met, a repeated measures univariate ANOVA could be performed. Otherwise, a repeated measures MANOVA was highly recommended. In the situation of a MANOVA indicating a significant difference and one of the two assumptions not being upheld, a subsequent univariate ANOVA could be performed for any two groups with conducting the Greenhouse-Geiser adjustments (Qiu et al., 2006).

In this question, sample statistical analysis of cadence 3 was presented. The EMG data were statistically analyzed in the following six steps: 1. Muscle activity percentage values were first evaluated for normality and for outliers. No excessive kurtosis or skewness (kurtosis or skewness score/standard error > 3.0) were found; two outliers was found (z scores > 3.0) for pectoralis major muscle and were removed; 2. Mauchly's Test of Sphecirity was run to check if there is an interaction between repeated measures. The assumption of Sphecirity was not upheld for pectoralis major, triceps brachii, deltoid, and upper trapezius ($P = 0.000 < 0.05$).The results were presented in Tables 4.12; 3. Means and standard deviations for the muscle activities of the four muscles were illustrated in Figures 4.13-4.15; 4. A repeated measures ANOVA was performed with an alpha level of 0.05. Tables 4.13 – 4.14 provided the test of between-subjects effects and multivariate tests of the muscles activities; 5. Boferroni Comparisons were performed to determine which of the three variants resulted in statistically significant values. Table 4.15 provided the results.

Table 4.12

Mauchly's Test of Sphecirity of the Muscle Activities for RQ 7

Pectoralis Major							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.443	17.914	2	.000	.642	.664	.500
Triceps Brachii							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.323	24.863	2	.000	.596	.610	.500
Deltoid							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.202	35.144	2	.000	.556	.564	.500
Upper Trapezius							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.442	17.984	2	.000	.642	.663	.500

Table 4.13

Test of Between-Subjects Effects of the Muscles Activities for RQ 7

Pectoralis Major						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	468173.261	1	468173.261	17904.901	.000	.999
Error	601.399	23	26.148			
Triceps Brachii						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	523639.667	1	523639.667	17892.075	.000	.999
Error	673.131	23	29.267			
Deltoid						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	648546.605	1	648546.605	11372.473	.000	.998
Error	1311.638	23	57.028			
Upper Trapezius						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	591781.337	1	591781.337	13766.001	.000	.998
Error	988.738	23	42.989			

Table 4.14

Multivariate Tests of the Muscles Activities for RQ 7

Multivariate Tests of Pectoralis Major						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.985	743.699	2.000	22.000	.000	.985
Multivariate Tests of Triceps Brachii						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.983	632.697	2.000	22.000	.000	.983
Multivariate Tests of Deltoid						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.997	3151.708	2.000	22.000	.000	.997
Multivariate Tests of Upper Trapezius						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.984	688.125	2.000	22.000	.000	.984

Table 4.15

Bonferroni Comparisons for the Muscles Activities for RQ 7

Pairwise Comparisons of Pectoralis Major						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	19.796*	1.547	.000	15.801	23.791
	3	44.917*	1.644	.000	40.672	49.161
2	**1**	-19.796*	1.547	.000	-23.791	-15.801
	3	25.121*	.695	.000	23.326	26.916
3	**1**	-44.917*	1.644	.000	-49.161	-40.672
	2	-25.121*	.695	.000	-26.916	-23.326
Pairwise Comparisons of Triceps Brachii						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	26.840*	2.278	.000	20.958	32.721
	3	48.712*	2.108	.000	43.270	54.155
2	**1**	-26.840*	2.278	.000	-32.721	-20.958
	3	21.873*	.800	.000	19.808	23.938
3	**1**	-48.712*	2.108	.000	-54.155	-43.270
	2	-21.873*	.800	.000	-23.938	-19.808
Pairwise Comparisons of Deltoid						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	35.485*	2.856	.000	28.111	42.860
	3	84.733*	2.495	.000	78.292	91.174
2	**1**	-35.485*	2.856	.000	-42.860	-28.111
	3	49.248*	.824	.000	47.122	51.374
3	**1**	-84.733*	2.495	.000	-91.174	-78.292
	2	-49.248*	.824	.000	-51.374	-47.122

Table 4.15 (cont'd)						
Pairwise Comparisons of Upper Trapezius						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	34.769*	2.149	.000	29.220	40.318
	3	57.971*	1.990	.000	52.834	63.108
2	**1**	-34.769*	2.149	.000	-40.318	-29.220
	3	23.202*	.907	.000	20.860	25.544
3	**1**	-57.971*	1.990	.000	-63.108	-52.834
	2	-23.202*	.907	.000	-25.544	-20.860

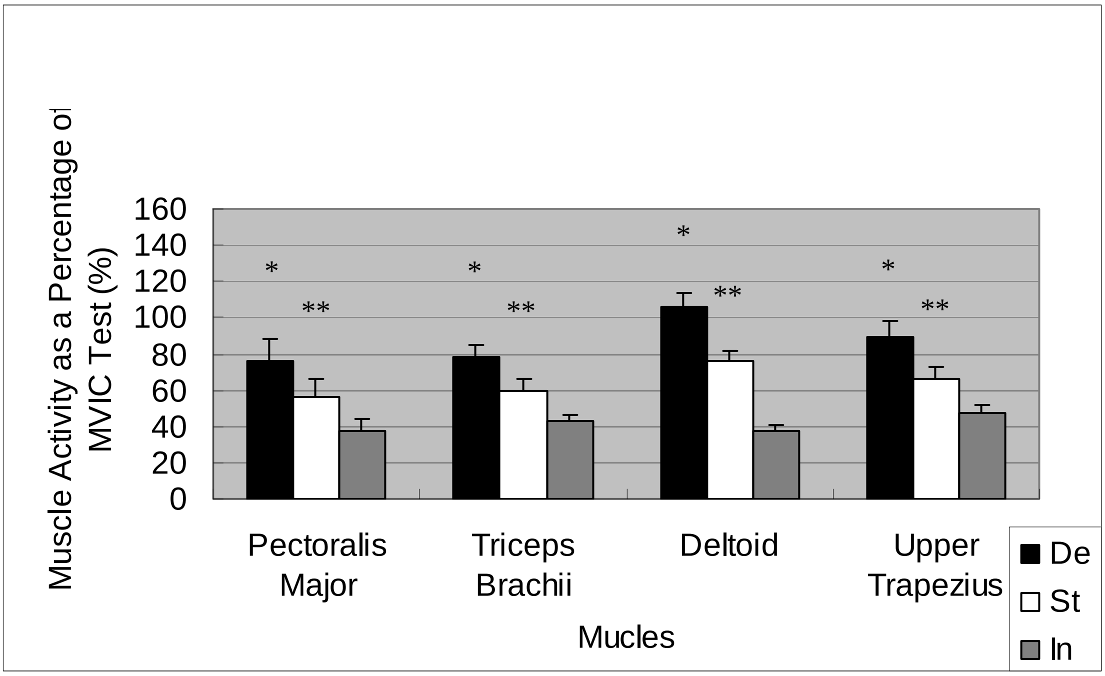

Figure 4.13 Means and standard deviations of full-wave rectified and integrated muscle activities as a percentage of Maximum Voluntary Isometric Contraction (MVIC) test in three push variants for cadence 1 (20 beats/minute)

De = Decline push-up;

St = Standard push-up;

In = Incline push-up;

* = Significantly different than St and In

** = Significantly different than In

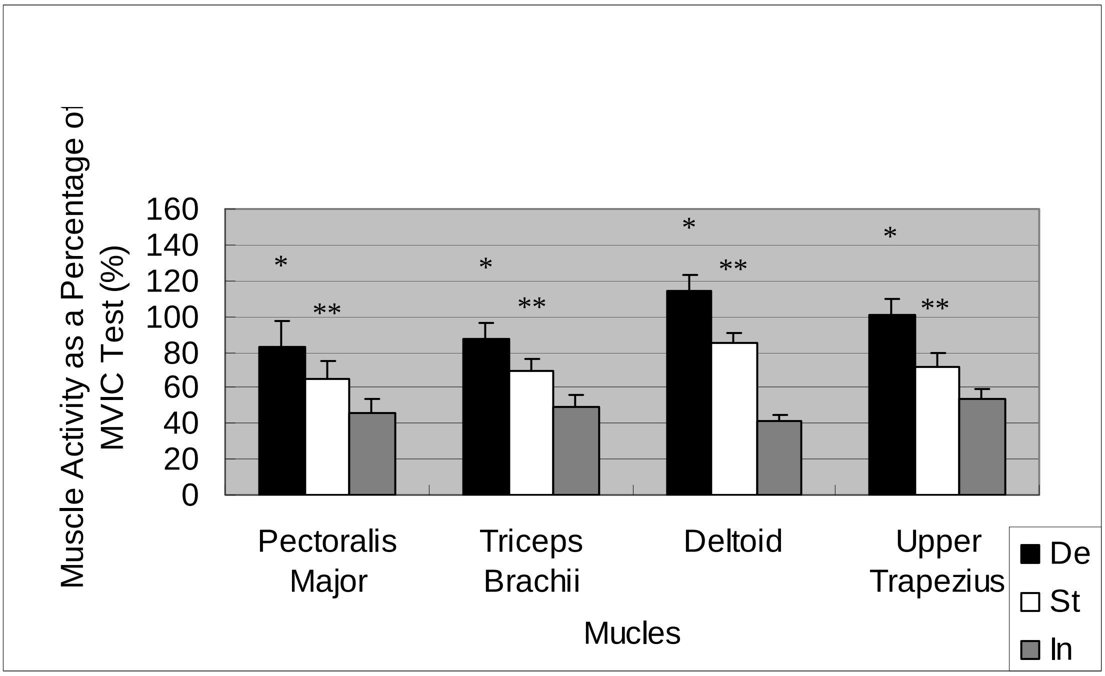

Figure 4.14 Means and standard deviations of full-wave rectified and integrated muscle activities as a percentage of Maximum Voluntary Isometric Contraction (MVIC) test in three push variants for cadence 2 (30 beats/minute)

De = Decline push-up;

St = Standard push-up;

In = Incline push-up;

* = Significantly different than St and In

** = Significantly different than In

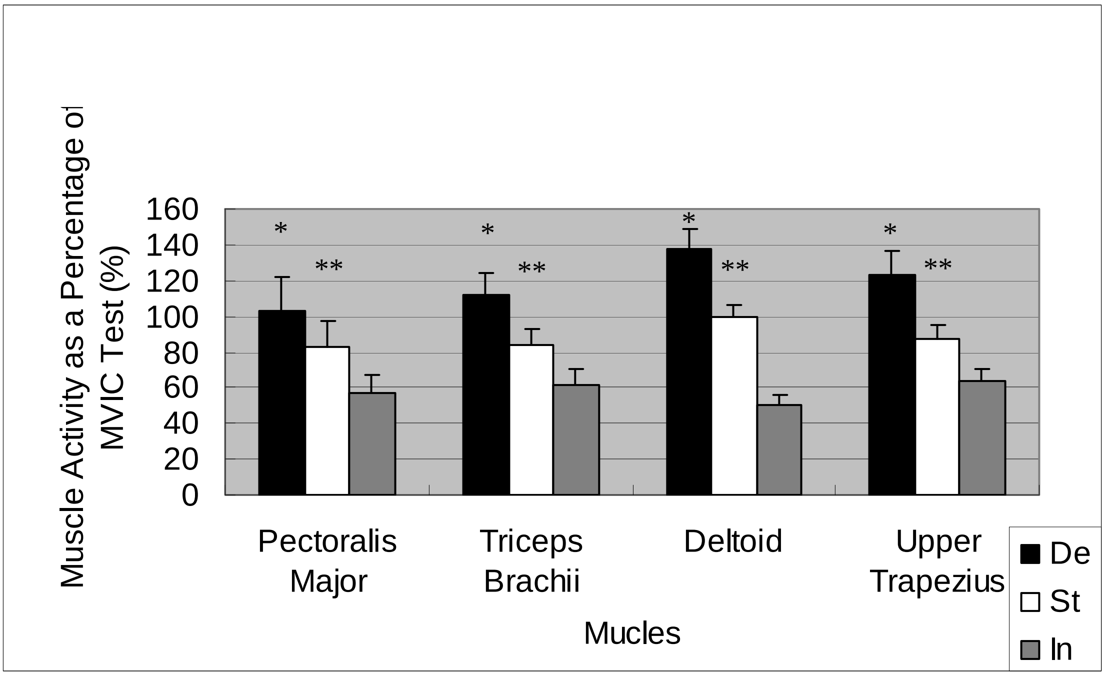

Figure 4.15 Means and standard deviations of full-wave rectified and integrated muscle activities as a percentage of Maximum Voluntary Isometric Contraction (MVIC) test in three push variants for cadence 3 (60 beats/minute)

De = Decline push-up;

St = Standard push-up;

In = Incline push-up;

* = Significantly different than St and In

** = Significantly different than In

Results showed that changes in the body angle had a very important effect on the muscle activation level. In all three cadences, muscle activities of the four selected muscles showed statistically significant difference between incline/standard push-ups, incline/decline push-ups, and standard/decline push-ups.

***RQ8**. How will electromyographic activity of selected muscles differ under the three different cadences when normalized to MVIC test?*

The three maximum hand forces from the second push-up in three push-up repetitions of each trial for all 24 participants were used for this research question. Here the decline push included two angles: 0 and -10 degrees. The maximum hand forces for these two angles were averaged first and then used in the statistical analysis in all three cadences. The maximum hand forces for the incline push-up were processed in the same way.

The basic method of performing statistical analysis for this question was to conduct ANOVA first to examine if there were any differences between dependent variables' means. If ANOVA indicated a P value less than 0.05, then Boferroni Comparisons were conducted to find out which two groups had a statistically significant difference. Because this study had several independent variables (body angles and cadences) and dependent variables (forces and EMG signals), each independent variable had more than two levels (e.g., three cadences), and repeated measures were made at different time points with each participant contributing seven scores each time, so a repeated measures Analysis of Variance (ANOVA) was selected.

Two assumptions need to be upheld for conducting a repeated measures ANOVA: the assumption of Normality and Mauchly's Test of Sphecirity. Only under the condition that these two assumptions were met, a repeated measures univariate ANOVA could be performed. Otherwise, a repeated measures MANOVA was highly recommended. In the situation of a MANOVA indicating a significant difference and one of the two assumptions not being upheld, a subsequent univariate ANOVA could be performed for any two groups with conducting the Greenhouse-Geiser adjustments (Qiu et al., 2006).

In this question, sample statistical analysis of the incline push-up was presented. The EMG data were statistically analyzed in the following six steps: 1. Muscle activity percentage values were first evaluated for normality and for outliers. No excessive kurtosis or skewness (kurtosis or skewness score/standard error > 3.0) and no outliers (z scores < 3.0) were found; 2. Mauchly's Test of Sphecirity was run to check if there was an interaction between repeated measures. The assumption of Sphecirity was not upheld for pectoralis major and deltoid (P = 0.000 < 0.05), but upheld for triceps brachii and upper trapezius (P = 0.550 and 0.161 > 0.05).The results were presented in Tables 4.16; 3. Means and standard deviations for the muscle activities of the four muscles were illustrated in Figures 4.16-4.18; 4. A repeated measures ANOVA was performed with an alpha level of 0.05. Tables 4.17 – 4.18 provided the test of between-subjects effects of the muscles activities and multivariate tests of the muscles activities; 5. Boferroni Comparisons was performed to determine which of the three cadences resulted in statistically significant values. Table 4.19 provided the results.

Table 4.16

Mauchly's Test of Sphecirity of the Muscle Activities for RQ 8

Pectoralis Major							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.618	10.594	2	.005	.724	.759	.500
Triceps Brachii							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.947	1.195	2	.550	.950	1.000	.500
Deltoid							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.681	8.445	2	.015	.758	.801	.500
Upper Trapezius							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.847	3.647	2	.161	.867	.932	.500

Table 4.17

Test of Between-Subjects Effects of the Muscles Activities for RQ 8

Pectoralis Major						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	159866.851	1	159866.851	18771.818	.000	.999
Error	195.875	23	8.516			
Triceps Brachii						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	188779.522	1	188779.522	55953.319	.000	1.000
Error	77.599	23	3.374			
Deltoid						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	133842.757	1	133842.757	112357.163	.000	1.000
Error	27.398	23	1.191			
Upper Trapezius						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	216235.320	1	216235.320	66059.213	.000	1.000
Error	75.287	23	3.273			

Table 4.18

Multivariate Tests of the Muscles Activities for RQ 8

Multivariate Tests of Pectoralis Major						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.973	394.784	2.000	22.000	.000	.973
Multivariate Tests of Triceps Brachii						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.980	533.553	2.000	22.000	.000	.980
Multivariate Tests of Deltoid						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.968	336.615	2.000	22.000	.000	.968
Multivariate Tests of Upper Trapezius						
	Value	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Pillai's trace	.990	1074.626	2.000	22.000	.000	.990

Table 4.19

Bonferroni Comparisons for the Muscles Activities for RQ 8

Pairwise Comparisons of Pectoralis Major						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	-8.275*	.907	.000	-10.617	-5.933
	3	-19.394*	.883	.000	-21.673	-17.115
2	**1**	8.275*	.907	.000	5.933	10.617
	3	-11.119*	.484	.000	-12.369	-9.868
3	**1**	19.394*	.883	.630	17.115	21.673
	2	11.119*	.484	.545	9.868	12.369
Pairwise Comparisons of Triceps Brachii						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	-5.954*	.472	.000	-7.173	-4.735
	3	-18.798*	.563	.000	-20.251	-17.344
2	**1**	5.954*	.472	.000	4.735	7.173
	3	-12.844*	.572	.000	-14.321	-11.367
3	**1**	18.798*	.563	.630	17.344	20.251
	2	12.844*	.572	.545	11.367	14.321
Pairwise Comparisons of Deltoid						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	-4.115*	.281	.000	-4.839	-3.390
	3	-12.756*	.481	.000	-13.998	-11.515
2	**1**	4.115*	.281	.000	3.390	4.839
	3	-8.642*	.398	.000	-9.668	-7.615
3	**1**	12.756*	.481	.000	11.515	13.998
	2	8.642*	.398	.000	7.615	9.668

Table 4.19 (cont’d)						
Pairwise Comparisons of Upper Trapezius						
(I) Time	**(J) Time**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
1	**2**	-5.608*	.500	.000	-6.899	-4.318
	3	-16.004*	.349	.000	-16.905	-15.104
2	**1**	5.608*	.500	.000	4.318	6.899
	3	-10.396*	.455	.000	-11.570	-9.222
3	**1**	16.004*	.349	.873	15.104	16.905
	2	10.396*	.455	.659	9.222	11.570

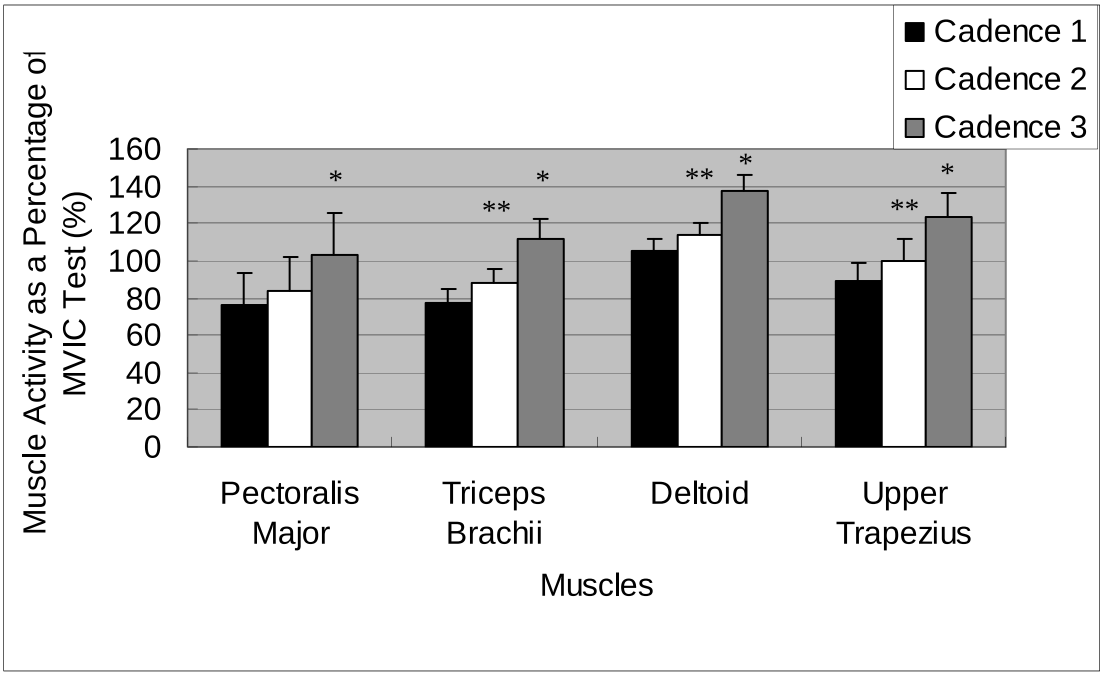

Figure 4.16 Means and standard deviations of full-wave rectified and integrated muscle activities as a percentage of Maximum Voluntary Isometric Contraction (MVIC) test in the three cadences for the decline push-up

Cadence 1 = 20 beats/min = three seconds for eccentric and eccentric

Cadence 2 = 30 beats/min = two seconds for eccentric and eccentric

Cadence 3 = 60 beats/min = one second for eccentric and eccentric

M1 = Pectoralis Major; M2 = Triceps Brachii;

M3 = Deltoid; M4 = Upper Trapezius;

* = Significantly different than Cadence 1 and Cadence 2

** = Significantly different than Cadence1

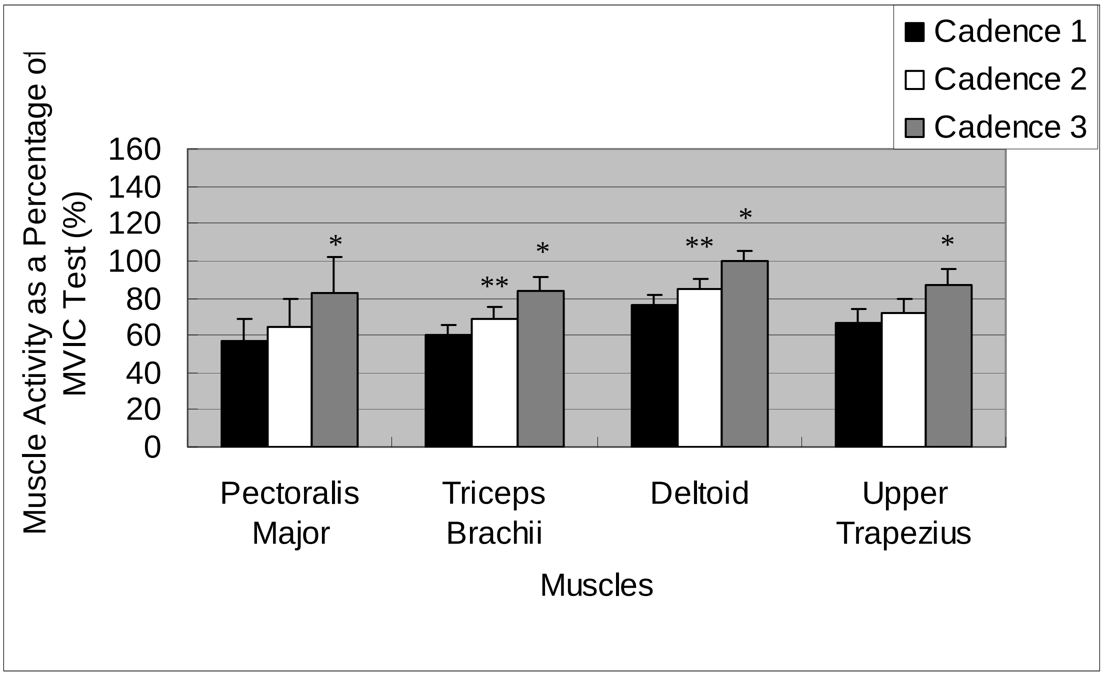

Figure 4.17 Means and standard deviations of full-wave rectified and integrated muscle activities as a percentage of Maximum Voluntary Isometric Contraction (MVIC) test in the three cadences for the standard push-up

Cadence 1 = 20 beats/min = three seconds for eccentric and eccentric

Cadence 2 = 30 beats/min = two seconds for eccentric and eccentric

Cadence 3 = 60 beats/min = one second for eccentric and eccentric

M1 = Pectoralis Major; M2 = Triceps Brachii;

M3 = Deltoid; M4 = Upper Trapezius;

* = Significantly different than Cadence 1 and Cadence 2

** = Significantly different than Cadence1

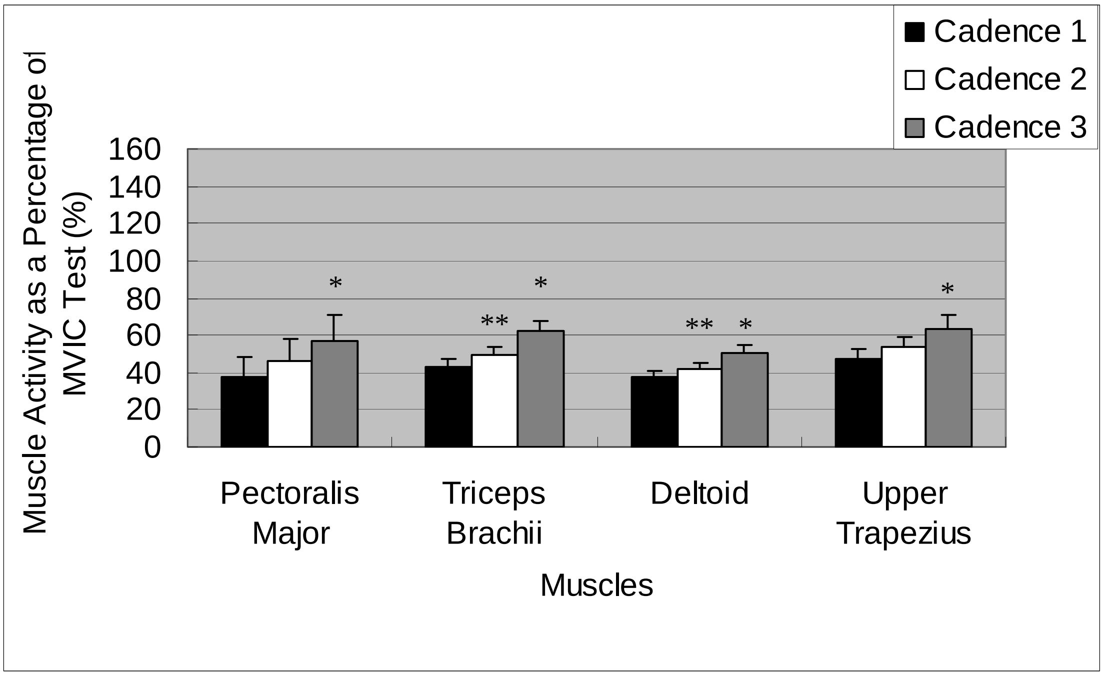

Figure 4.18 Means and standard deviations of full-wave rectified and integrated muscle activities as a percentage of Maximum Voluntary Isometric Contraction (MVIC) test in the three cadences for the incline push-up

Cadence 1 = 20 beats/min = three seconds for eccentric and eccentric

Cadence 2 = 30 beats/min = two seconds for eccentric and eccentric

Cadence 3 = 60 beats/min = one second for eccentric and eccentric

M1 = Pectoralis Major; M2 = Triceps Brachii;

M3 = Deltoid; M4 = Upper Trapezius;

* = Significantly different than Cadence 1 and Cadence 2

** = Significantly different than Cadence1

Results showed that the deltoid and triceps brachii muscles were always statistically significantly different between cadence 1/cadence 2, cadence 1/cadence 3, and cadence 2/cadence 3 in all three push-ups. The upper trapezius muscle was statistically significantly different between cadence 1/cadence 2, cadence 1/cadence 3, and cadence 2/cadence 3 only in the decline push-up, was statistically significantly different between cadence 1/cadence 2 and cadence 1/cadence 3 in the incline and standard push-up. The pectoralis major muscle was only statistically significantly different between cadence 1/cadence 2 and cadence 1/cadence 3 in all three push-ups.

CHAPTER 5 DISCUSSION

This study evaluated the effects of the body angle and cadence, in performances of the push-up, on maximum hand forces and electromyographical activity from the pectorali major, triceps brachii, deltoid, and upper trapezius. In this chapter the steps that were taken to minimize the threats to internal and external validity are reported. Each of the eight proposed research question is discussed on the basis of the results reported in CHAPTER 4. At the end of the current chapter, practical applications of the study for coaches and physical therapists, limitations of the study, and direction for the future study are discussed.

Minimizing Threats to Validity

Minimizing threats to internal validity

History, maturation, testing, instrumentation, and experimental mortality were threats to internal validity in this study. The following paragraphs contain a presentation of the attempts that were used to minimize these threats. Although statistical regression and selection bias were also threats to internal validity, they did not apply to this study because the research was a repeated measure design with only one group of participants (all the participants received the same treatment).

History. History refers to specific things that happen while conducting the research study that affect the final scores of the participants in addition to the effect of the experimental treatment (Ted B. & Larry H., 2005). One of the history threats to this research is the different resting cycle for participants. Some participants with less muscle strength had a longer resting period of about five minutes, while participants with relatively more muscle strength had an average resting period of three minutes. Theoretically, a longer resting period could make participants have a better recovery and induce decreased EMG values; however, to make sure every participant could complete the entire testing, different resting cycles were necessary. To better control the internal validity, the current investigator observed the resting period for each participant and controlled the period as a constant one for each participant. The participants' activities prior to the testing were another history threat to this study. During recruitment, potential participants were asked via telephone about their current health problems (e.g., arthritis, hernias) and injuries (e.g., bone fracture, sprained wrist/ankle). Those who had problems that would adversely affect their push-up performance were excluded from the study. Four potential participants reported recent injuries, one was forearm bone fracture, two were sprained ankles, and one was ACL ligament tear. These four potential participants were excluded from participation. Previous health problems were considered on a case by case basis for possible exclusion. Since no potential participant was adversely affected by health problems no one was excluded for this reason. Instructions were given to all the qualified participants to make them refrain from any vigorous activity for 48 hours prior to the testing to minimize the effects of these activities on the testing results. Vigorous activity was defined as weight training of the upper extremity and any competitive sport activity (e.g., tennis match). Three questionnaires (see Appendix C) were given to the participants before the start of the testing, one of which was history of the participants, and the other two were medical information and pre-test activity. Information about the nature of physical activities during the last 48 hours and the amount of sleep that the participants had was obtained, because they were expected to have at least six hours of sleep the night prior to the testing. All participants enrolled in the study were free of health problems and injuries, refrained from vigorous activities for 48 hours prior to the testing, and had slept six to eight hours the day before being tested.

Maturation. Because the participants grow older during an experimental period, their performance levels may change and this change may be reflected in their final scores (Ted B. & Larry H., 2005). Maturation posed little threat to the internal validity of this study; because the data collection period was very short (within three hours). Thus, maturation effect was unimportant in this study.

Testing. The act of taking a test can affect the scores of the participants on a second or later testing. To some extent one reason why participants do better on a posttest is because they learn from a pre-test (Ted B. & Larry H., 2005). One way to minimize the testing threat to internal validity is to minimize the time of measurements to minimize the effect of learning. During the testing, it was attempted to have the total measurement time period controlled within three hours. However, two female participants were not able to follow the time frame, because their strength and endurance was less than needed to be successful in the three hours period. They were given additional break time between decline push-up trials. The most effective way to control this threat in this study is to standardize the push-up protocol. The specific techniques of performing the push-up, for example, the distance between the two hands, the angle of the fingers, and the pace, were all standardized and controlled. Therefore, even if the participants could learn from the first part of the testing, their performance in the latter part would not change much.

Instrumentation. Change in the adjustment or calibration of the measuring equipment or use of different standards among scores may cause differences among groups in final score or change in the scores of the participants over time (Ted B. & Larry H., 2005). To minimize the threat, all instrumentation was calibrated prior to data collection and was checked periodically (every three participants) to make sure the measurements were consistent. The biggest problem was the placement of EMG electrodes over the skin surface of selected muscles of different participants of different genders; because participant had different anthropometric characteristics and females had more adipose tissues which make it difficult locating the placement point. To minimize the threat, the placement of EMG electrodes was standardized with reference to body landmarks to make the placement more accurate. Additionally, an electrode placement chart (Criterion Inc., 2007) was used to help with locating body landmarks and placing electrodes.

Experimental mortality. This particular threat to internal validity is created with the excessive loss of participants so that experimental groups are no longer representative of a population or similar to each other (Ted B. & Larry H., 2005). In the current study there was no loss of participants, so the experimental mortality was not a threat to internal validity.

Expectancy error. The expectancy error was minimized by assigning participants to a random preplanned order of performance of the three cadences to decrease the bias. Theoretically, the order of the five body angles used for the incline, standard, and decline push-ups should have also been randomly assigned. However, due to the difficulty of changing positioning of angle adjustment box and performance board the body angle was not randomly changed for each random assignment of cadence. Basically, an easiest body angle was selected to be used for the random selection of the three push-up cadences. Then a second easiest body angle was selected from the remaining four for which three push-up cadences were randomly selected for a participant to perform. This process was continued until all five body angles with three push-up cadences had been performed. Additionally, four helpers were trained to assist with the testing. The helpers provided a consistent set of instructions to all participants to encourage them to perform their best for all push-up variants.

Minimizing threats to external validity

Interaction effect of testing. This effect occurs when the pre-test changes the group's response to the experimental treatment, thus making the group unrepresentative of any particular population and certainly unrepresentative of a population that has not been pre-tested. The biggest threat to the external validity in this study is the body angle and cadence interference, because most researches just focused on one cadence. However, considering the participants were given enough rest time between trials, the external validity was compensated.

Research Questions

RQ1.*For the incline push-up, is there a relationship between the maximum hand forces, as a percentage of body weight, and incline angle? When the incline angle increases, will the maximum hand forces decrease?*

Mean maximum hand forces were collected in three directions: anterior-posterior (Fx), medial-lateral (Fy), and perpendicular (Fz). Fx had an obvious decrease when the incline angle increased from 15 to 30 to 45 degrees. Pearson correlation coefficients for Fx for the three push-up cadences had values of -0.995, -1.000, -1.000, respectively. The negative values for each of these coefficients indicated that an increase in Fx was associated with a decrease in the body angle (an increase in the incline angle). These values were very close to -1 for all three cadences, showing a near perfect negative linear relationship between the Fx and incline angle. For Fy, mean maximum medial-lateral force, the relationship with changes in body angle was not obvious. Pearson correlation coefficients of 0.000, -0.500, and -0.866 were obtained for the three cadences. Fz (mean maximum perpendicular force) was the most important force in all three forces and had the highest magnitudes. This provided insight into how the perpendicular load was borne on the right hand during the incline push-up. It demonstrated a most dramatic relationship to the incline angle, with the Pearson correlation coefficients of -0.999, -0.999, and -1.000, respectively. The Pearson values demonstrated a near perfect negative linear relationship between the Fz and incline angle. The results were exactly as expected: during an incline push-up, when the incline angle increased, the hands would bear less perpendicular and anterior-posterior load due to more body weight being distributed to the support by the feet. However, because the body would not move much in the medial-lateral direction, due to the nature of the front leaning position in the incline push-up, the load in this direction did not change to an obvious extent.

RQ2*.For the decline push-up, is there a relationship between the maximum hand forces, as a percentage of body weight, and decline angle? When the decline angle increases, will the maximum hand forces increase?*

Mean maximum hand forces were collected in three directions: anterior-posterior (Fx), medial-lateral (Fy), and perpendicular (Fz). There were strong relationships between the maximum hand forces Fx and Fz and the decline angle. Fx had an obvious increase when the decline angle changed from positive fifteen degrees (standard push-up) to negative ten degrees. Pearson correlation coefficients were calculated for Fx and the values were -0.988 in all three push-up cadences. The negative values of each of these coefficients indicated that an increase in Fx was associated with a decrease in the body angle (an increase in the decline angle). These values were very close to -1 for all three cadences, showing a near perfect negative linear relationship between Fx and decline angle. For Fy, mean maximum medial-lateral force, the relationship with changes in body angle was not obvious. The Pearson correlation coefficients of 0.397, -0.115, and -0.115 were obtained for the three cadences. Fz (maximum perpendicular force) was the most important force in these three forces, which provided insight into how much perpendicular load was borne at the right hand during the decline push-up. It demonstrated a most dramatic relationship to the decline angle, with the Pearson correlation coefficient of -1.000, -1.000, and -0.999, respectively. The Pearson values demonstrated a perfect negative linear relationship between the Fz and decline angle. The results were exactly as expected: during a decline push-up, when the decline angle increased, the hands would bear more perpendicular and anterior-posterior load due to less body weight distributing to the feet. Or simply speaking, with a steeper decline, there would be greater portion of the body load supported by the hands and a less portion supported by the interface of the feet with the supporting surface. However, because the body would not move much in the medial-lateral direction due to the nature of the front leaning position in the decline push-up, the load in this direction did not change to an obvious extent.

RQ3*. Which muscle among pectoralis major, triceps brachii, deltoid, and upper trapezius is relatively most active in comparison to its recorded Maximum Voluntary Isometric Contraction (MVIC) during the typical standard push-up with cadence 2 (30 beats/minute)?*

This study generated a very interesting result that was different from what coaches usually thought – the pectoralis major muscle was not the most relatively active muscle during a push-up exercise. Or, in other words, instead of the pectoralis major, the deltoid muscle was the relatively most active one and benefited the most from the push-up exercise. The study found that the mean EMG value of the 24 participants, represented as a percentage of the MVIC test, for the deltoid was 85.3% in a standard push-up performed at cadence 2, while the EMG value for next active muscle, upper trapezius, was 72.1%. The third relatively most active muscle, triceps brachii, was using 68.9% of the maximum voluntary isometric contraction. And the pectoralis major, which was the most inactive one, only used 64.5% of the MVIC. The order of muscle activity was in agreement with the findings from Hinson (1969), who found that the order of muscle involvement in a push-up exercise was the deltoid followed by the triceps brachii, trapezius, and clavicular portion of the pectoralis major. However, the EMG contribution values for these muscles in the current study were not the same as reported by Hinson (1969). In her study the deltoid muscle was using about 74% of the maximum strength, trapezius 45%, triceps brachii 42%, and pectoralis major only 37% (see Table 5.2). The EMG values in the current study were more consistent with those reported by Cogley et al. (2005), who recorded a 63.8% value for pectoralis major and 69.2% for triceps brachii. The dramatic change in EMG values might due to differences in the preparation of the electrode sites, the placement of the EMG electrodes, and adiposity of the participants. Although the pectoralis major was not the most active muscle during the push-up as postulated by others, it was still hard to say it was the most inactive one. The lower portion of the pectoralis major had a lot of adipose tissue, especially for females, so the EMG data collected from this site might be compromised. Considering the EMG values from the pectoralis major and triceps brachii were very close, more research needs to be done to investigate muscle activity of the pectoralis major.

RQ4*.Will the recruitment pattern of selected muscles (pectoralis major, triceps brachii, deltoid, and upper trapezius) be different in the incline and decline push-up at cadence 2 (30 beats/minute)?*

For the deltoid muscle, the recruitment pattern was different in the incline push-up compared with that in the decline push-up (see Figure 4.8). A more persistent exertion of the deltoid and earlier muscle activation to maximum strength could be seen for the decline push-up. This was reasonable due to two reasons: one was that the decline push-up was a more challenging variant and thus a more persistent exertion was a requirement; the other reason is that in the decline push-up, because of the transfer of the body center of gravity, the upper extremity was bearing a larger portion of body weight and the deltoid was placed at a more important position to control the body balance in the anterior-posterior direction. This induced earlier deltoid muscle activation to maximum strength in this variant. For the upper trapezius muscle, the recruitment pattern did not change much during these two push-up variants, only a larger EMG magnitude could be seen in the decline push-up. The EMG from the pectoralis major muscle was the most unstable one, which could be seen from the dramatically different EMG magnitude. However, the general pattern of the recruitment was consistent in these two push-up variants. For the triceps brachii muscle, one or two strength burst during the eccentric phase could be seen in the decline push-up due to this variant causing more challenge; the rest of the recruitment pattern was consistent in the two variants. In general, only the recruitment pattern of the deltoid and triceps brachii changed during the incline and decline push-up.

RQ5*.Will different performance cadences change the maximum hand forces (Fx, Fy, and Fz), as a percentage of body weight, that occur during the incline, standard, and decline push-ups?*

In the incline push-up, maximum anterior-posterior force (Fx) was significantly different in cadence 1 (20 beats/minute) relative to cadence 3 (60 beats/minute). However, change from cadence 1 to cadence 2 (30 beats/minute) did not change maximum Fx significantly. Maximum Fz in the incline push-up was significantly different in all three cadences, demonstrating that the perpendicular force was more sensitive to the cadence change. As shown in the Boferroni, maximum Fz was significantly different in cadence 1/cadence 2, cadence 1/cadence 3, and cadence 2/cadence 3.

In the standard push-up, maximum Fx and Fz mirrored that in the incline push-up.

In the decline push-up, maximum Fx was significantly different in all three cadences, and so was maximum Fz. This indicated that as the body angle decreases, or in other words, when the task became difficult, the sensitivity of the maximum Fx increased.

In the incline, standard, and decline push-up, the maximum Fy did not change in a predictable way with changes in performance cadence. As previously discussed in research questions one and two (RQ1 and RQ2), due to the nature of the push-up motion focusing on up and down movement and the symmetrical support from the two hands, the medial-lateral force was relatively stable and did not change much in magnitude with changes in cadence. So through statistical analysis, there were no significant differences in the maximum Fy when the cadence changed.

In general, change in the performance cadence dramatically changed the perpendicular force; there is a direct relationship between frequency of push-up and maximum perpendicular force experienced at the hand-surface interface. From a mechanical perspective, an increase in frequency of push-up will induce an increased magnitude in acceleration of the mass of the body; because F = ma, the increase of the acceleration will definitely increase the force value. Therefore, the results of this study were consistent with the theory. From this relationship it might be conjectured that a high-cadence push-up is more likely to induce an upper extremity injury. Anterior-posterior force Fx was not as sensitive as Fz to the cadence change.

RQ6*.How does the pattern of the maximum perpendicular hand force (Fz) change from the incline push-up to decline push-up?*

According to Ikawa & Tokuhiro (1995), the axial elbow force of a typical push-up cycle could be divided into seven phases with eight mark points. Point #1 was the static force required to hold the “up” position prior to starting a push-up set, the mean axial force for this position was 36.8% of body weight in their records. Upon initiating descent of push-up, there was a decrease in Fz corresponding to point # 2. As the participant descended, Fz increased in magnitude until obtaining the “down” position of the push-up at point #3. Point #4 and #5 defined the region of decreased force required to hold this “static down” position. Maximum point #6 was reached as the participant attempted to raise the body from the “down” position. As the participant ascended from the floor, the axial force decreased to a minimum at point #7 and then returned to point #8, in which the participant held in the static “up” position.

In the graph from the current study, the perpendicular hand force of a typical push-up cycle could be divided into five phases with six mark points. Point #1 is the dynamic force required to move through the “up” position at the start of the eccentric phase (Note that the participants in the current study performed three consecutive push-ups and were told not to lock out the elbow joints at the beginning of the eccentric phase/end of the concentric phase). Upon initiating descent of push-up, there was a decrease in Fz corresponding to point #2. As the participant descended, Fz increased in magnitude until obtaining the “down” position of the push-up at point #3. Point #4 defined the region of decreased force required to hold this “static down” position. Maximum point #5 was reached as the participant attempted to raise the body from the “down” position (transition from the eccentric phase to the concentric phase). As the participant ascended from the floor, the axial force decreased to a minimum at point #6 (see figure 5.1).

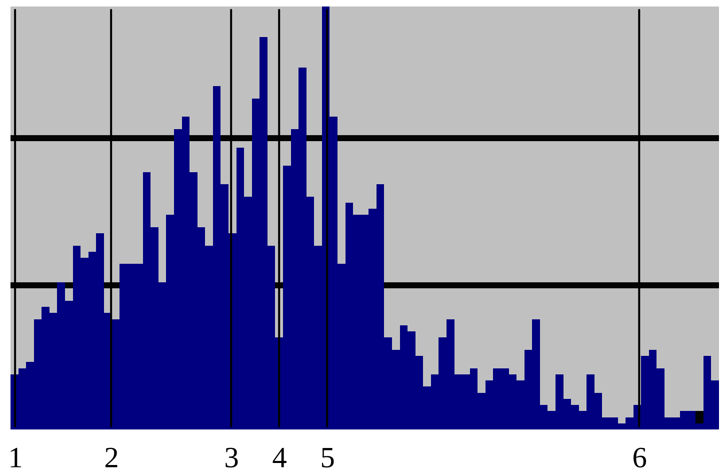

Figure 5.1 Typical perpendicular force Fz pattern and six mark points

In both the incline and decline push-up of the current study, the basic phases were the same for Fz (see Table 5.1). However, in the decline push-up, there appeared relatively larger Fz values during the phase between point #2 and #3, while in the incline push-up there were not relatively larger values. This pattern change was reasonable because the body’s center of gravity was partially shifted anteriorly in the decline push-up thus induced larger Fz values. In addition, the greater difficulty of performing decline push-ups in some cases caused instability as visually evident muscle “shaking” generating larger Fz values during the phase between points #2 and #3.

Table 5.1

Force at Hand-surface Interface as a Percent of Body Weight for Incline, Standard, and Decline Push-ups with Different Cadences and Body Angles

			Cadence		
			1	**2**	**3**
		Beats/min:	**20**	**30**	**60**
		Push-ups/min:	**10**	**15**	**30**
Type of Push-up	**Body Angle (deg)**	**Direction of Force**			
Decline	**-10**	**Fx （%）**	14.9±1.2	18.2±1.1	22.9±3.3
		Fy （%）	7.56±0.5	7.80±0.5	8.20±0.6
		Fz （%）	60.1±7.8	66.5±8.9	73.1±9.0
	0	**Fx （%）**	11.2±0.9	14.1±1.0	18.9±1.8
		Fy （%）	7.54±0.6	7.82±0.8	8.12±0.3
		Fz （%）	52.5±7.2	58.8±4.3	64.4±4.5
Standard	**≅15**	**Fx （%）**	8.00±0.7	10.8±0.5	15.4±1.1
		Fy （%）	7.51±0.8	7.80±0.3	8.08±0.3
		Fz （%）	40.3±5.3	45.6±3.2	53.2±4.2
Incline	**30**	**Fx （%）**	6.30±0.4	8.80±1.1	12.3±0.1
		Fy （%）	7.50±0.7	7.79±0.5	8.05±0.5
		Fz （%）	30.4±4.1	33.0±2.0	40.9±3.4
	45	**Fx （%）**	5.10±0.3	6.60±0.2	9.40±0.8
		Fy （%）	7.51±0.6	7.79±0.9	8.04±0.6
		Fz （%）	18.6±1.2	21.9±1.8	29.3±2.2

Note all values are represented as a percent of body weight,
Fx = anterior-posterior force, Fy = medial-lateral force, Fz = perpendicular force.

RQ7.*How will electromyographic activity of selected muscles differ among the incline, standard, and decline push-ups when normalized to MVIC test?*

All four muscles (pectoralis major, triceps brachii, deltoid, and upper trapezius) showed differences in elecrtomyographic activity when participants changed their body angle to perform incline, standard, and decline push-ups (see Table 5.2). This result was what the current author expected from this study (i.e., incline and decline body angle changes would dramatically change muscle activation level). Significant changes observed in EMG activity was most likely related to changes in the joint reaction forces caused by the changed load at the hand-surface interface associated with variations in body angle. Coaches and physical therapists could benefit from the findings of this research question (i.e., the electromyographic activity of the selected muscles were very sensitive to body angle changes in the push-up exercise, especially in the decline push-up). Through careful examination of the research data, the author found that a change of 15 degrees in the body angle could induce a change of 7%-20% in muscle activity, depending on what cadence was used. The faster the pace, the more change occurred with the body angle. Coaches and physical therapists could use this understanding to aid them in assigning/prescribing specific push-up variants as part of a progressive resistance program to build strength and to reduce the chance of injury and/or re-injury. For clinical specialists, this study provides insight into the careful use of variations of the push-up to support the needs of patients during upper extremity rehabilitation programs.

RQ8*.How will electromyographic activity of selected muscles differ under the three different cadences when normalized to MVIC test?*

In the incline push-up, electromyographic muscle activity of pectoralis major was significantly different in cadence 1 (20 beats/minute) relative to cadence 3 (60 beats/minute) (see Table 5.2). However, change from cadence 1 to cadence 2 (30 beats/minute) did not significantly change muscle activity of pectoralis major. This situation held true for muscle activity of the trapezius. EMG activity of the deltoid and triceps brachii were significantly different in all three cadences, demonstrating that these two muscles were more sensitive to the cadence change in the incline push-up.

In the standard push-up, EMG values of all four muscles mirrored that in the incline push-up.

In the decline push-up, EMG values of triceps brachii, deltoid, and upper trapezius were all significantly different in all three cadences. This indicated that as the body angle decreased, or in other words, when the task became difficult, the upper trapezius became more sensitive to the cadence change. However, the muscle activity of the pectoralis major was still only significantly different between cadence one and three, demonstrating the pectoralis major muscle was the least sensitive muscle to cadence change.

In general, the more demanding fast pace push-ups required higher muscle activation levels. The result from this research question was quite consistent with that reported by Freeman et al. (2006), who found that in a standard push-up, the EMG value for the pectoralis major was 33.1% in a slow pace, 38.3% in a normal pace, and

55.0 for a fast pace. The same result occurred in this study in that EMG values for the triceps brachii, anterior deltoid, and biceps brachii increased with cadence increase.

Table 5.2

Full Wave Rectified and Integrated EMG Activity for Incline, Standard, and Decline Push-ups with Different Cadences and Body Angles as a Percent of Maximum Voluntary Isometric Contraction (MVIC) Test (±standard deviations) for Corresponding Muscles and Time Periods

			Cadence		
			1	**2**	**3**
		Beats/min:	**20**	**30**	**60**
		Push-ups/min:	**10**	**15**	**30**
Type of Push-up	**Body Angle (deg)**	**Muscle**			
Decline	**-10**	**Pectoralis major（%）**	79.9±5.3	86.2±4.6	108.6±11.5
		Triceps brachii（%）	80.7±9.2	90.7±5.6	116.5±9.4
		Deltoid（%）	115.0±13.2	120.8±9.3	150.8±18.6
		Upper trapezius（%）	96.6±7.3	108.4±15.4	129.7±13.0
	0	**Pectoralis major（%）**	72.5±6.6	80.5±7.2	98.3±7.9
		Triceps brachii（%）	74.9±5.5	84.9±8.9	107.6±8.2
		Deltoid（%）	95.8±6.3	106.6±12.2	124.6±13.8
		Upper trapezius（%）	81.9±7.6	92.3±6.5	116.3±10.7
Standard	**≅15**	**Pectoralis major（%）**	56.6±3.3	64.5±4.5	82.4±6.8
		Triceps brachii（%）	59.9±6.0	68.9±5.6	83.6±10.2
		Deltoid（%）	76.3±5.8	85.3±9.7	99.5±6.6
		Upper trapezius（%）	66.7±5.0	72.1±8.8	86.8±6.7
Incline	**30**	**Pectoralis major（%）**	45.7±3.9	52.2±4.4	60.5±5.6
		Triceps brachii（%）	50.1±3.2	55.5±6.1	64.7±4.3
		Deltoid（%）	44.2±3.8	50.8±4.5	60.6±5.1
		Upper trapezius（%）	54.8±3.4	59.6±3.8	66.8±5.6
	45	**Pectoralis major（%）**	30.1±2.1	40.0±3.6	54.1±4.5
		Triceps brachii（%）	35.8±2.2	42.3±4.0%	58.8±6.1
		Deltoid（%）	30.8±2.8	32.4±3.6	39.9±3.4
		Upper trapezius（%）	40.4±2.2	46.8±3.2	60.4±4.5

Implications for Coaches and Physical Therapists

1. The pectoralis major muscle is not the relatively most involved muscle during the standard push-up. This study supports the deltoid as being relatively most active during the decline and standard push-up exercise.
2. To build a strong deltoid and upper trapezius muscle, the decline push-up is a good choice for weight training.
3. For coaches who want to achieve a maximum upper extremity training effect, the decline push-up is more preferable than the incline push-up.
4. For physical therapists who want a moderate training effect for patients' rehabilitation, the incline push-up is a more appropriate exercise than the decline push-up.
5. A high cadence will induce more muscle activities during the push-up exercise. For athletes who concentrated in a sport requiring more explosive strength, high-cadence push-ups (e.g., push-ups with one second concentric and eccentric phase) are more appropriate.
6. When coaches asked athletes to do decline push-ups, there might be increased chances of upper extremity joint injuries considering forces were of greater magnitude with greater decline angles.
7. For common people who want some advice on daily workouts, this study provided a quantitative guidance on muscle activity and a detailed instruction on the specific techniques of performing push-up variants.

Significance of the Research

Significance and novelty of this research focused on several points: 1. this study makes the hand load and muscle activity in the incline and decline push-up quantitative with different body angles and performance cadences. Although previous research investigated the percent of body weight at the wrist and elbow joint and muscle activities, they did not explore the effects of the body angle and cadences. In this research, complete tables (see Table 5.1 and 5.2) of very specific values of hand forces and muscles activities were provided; these information may provide significant guidance to coaches, athletes, physical therapists, and even common people. For example, if a physical therapist wants his patient to exert at 80% of chest muscle strength, a 2-2 cadence decline push-up at 0 degree can be selected. 2. This study clearly defined performance details of the standard, incline, and decline push-up. Previous research on push-up variants did not define how to measure the distance between two hands as shoulder-width and the foot position. In this study, all detailed information was clearly defined and may provide important guidance to many people.

Future Research

1. This study should be repeated with a focus on more decline angle push-ups, since very few studies were conducted on this topic.

2. This study could be conducted with additional emphasis on the effects of cadence. Only two studies were found in the literature that explored the effects of cadences on the push-up exercise.
3. This study demonstrated that fatigue is a problem during the performance of the decline push-up. In the future study, fatigue as a threat to internal validity should be minimized.
4. This study should be conducted with elite athletes. With a higher training level, they might exhibit a more stable and consistent response to the experimental treatment.
5. This study did not evaluate strength and/or endurance increases after incline and decline push-up training. Future research comparing the effects of these two push-up variants on gains in muscle strength and endurance would provide coaches and physical therapists with additional insight in the use of push-up.
6. This study did not evaluate the recovery level (post-exercise soreness) after the incline and decline push-ups, which can be a future direction.
7. If the incline push-up is better for recovery than the decline push-up?
8. Since the medial-lateral force did not play an important role in the push-up exercise, this force is not necessary to be collected in some studies.

Limitations

1. It was difficult to recruit participants with adequate muscle strength to perform the decline push-up with a negative ten degree body angle. Physically stronger participants may have been able to more consistently perform the decline push-ups.
2. The cadence in the study could not be perfectly followed by each participant, especially cadence 1, the slowest pace. Some participants had a good sense of pace, but some did not. A total of seven participants were off beat during the performance, and they repeated the off beat testing. The act of being off beat with the metronome was defined by the assistants who closely monitored the participants. If the assistants found the participants were faster or delayed for about one second or longer, they called stop. Repeating one or more sets of push-ups may cause fatigue of the participant, inducing larger EMG values.
3. The finishing movement of the concentric phase was not strictly controlled. Some participants may lock their elbow joints at this point.
4. This study included six female participants. The inaccuracy produced from EMG electrode placement on the pectoralis major might compromise the validity of data. Because females have more adipose tissues on this site.
5. During the testing, the participants had an EMG belt unit, EMG electrodes and wires, tape, and an electrogoniometer attached to their bodies. This equipment might have interfered with their natural push-up movement and differentiate the participants' performances from that of the daily training. Lighter weight electrogoniometer and EMG equipment are suggested for future study.

APPENDICIES

Appendix A

Consent/Assent Forms and Application for IRB Approval

Consent Form

"Kinetic, Kinematic and Electromyographical Analysis of Incline and Decline Push-ups with Different Cadences."

Primary Investigator: Eugene W. Brown, Ph. D, Department of Kinesiology, Michigan State University
Secondary Investigator: Keke Yang, doctoral student, Department of Kinesiology, Michigan State University

This study is being conducted as a doctoral dissertation:

This study of the push-up motion has several purposes: (a) examine three maximum hand forces experienced at the right hand and the perpendicular force pattern in different body angles; (b) compare the maximum hand forces at three performance frequencies; (c) investigate how selected muscles used in push-ups will be involved at different body angles; and (d) evaluate the effects of cadences on the muscles' activation levels and patterns. The primary goal of this study is to examine the effects of the body angle and performance cadence on hand forces and muscle activation to provide a better understanding of the incline and decline push-up.

You are being recruited for this study because you have experience with strength training and push-up techniques being evaluated. Evaluation of these different push-up techniques may, in general, allow you to better understand the benefits of this exercise and to more appropriately use it. Your total time commitment for this study will be approximately two and half hours. After the participant information phase, you will be asked to participate in the familiarization and testing phases scheduled on the same date. The estimated time for each of the three phases is 30, 60 and 60 minutes, respectively. In addition, it is imperative that participants be free of any orthopedic conditions that may hinder their ability to perform incline and decline push-ups. Additional details of each phase follow:

1) **Participant Information and Preparation Phase**-After explanation and description of the study, the consent form and questionnaires will be distributed among the participants to collect information to determine if there are any previous or current injuries/illnesses that should exclude the individual from the study. This assessment will be administered prior to the collection of body measurements. All body dimension data will be collected in private in the Department of Kinesiology's Biomechanics Research Station (approximately 50 minutes).
   - Body weight will be measured on a standard weight balance.
   - Standing height will be measured with a standard tool.
   - Sitting height will be measured while you are seated on a bench.
   - Segmental lengths will be determined with the use of standard measurement tools. Specifically, arm, forearm, and hand length and

wrist, elbow and shoulder width will be measured.

2) **Familiarization Phase**-This phase begins with you performing Jumping Jacks for one minute as a warm up followed by six types of stretching. The following step is to prepare you for the electrogoniometer installation and for EMG data collection by shaving and attaching electrodes on your trunk and upper extremities. You will be prepared for the placement of surface electrodes on five muscles. Each electrode placement site will be approximately two square inches. Preparation of these sites will involve cleaning with rubbing alcohol and light abrading of the skin. In the next step the electrogoniometer will be installed at your elbow joint and you will perform a MVIC (Maximum Voluntary Isometric Contraction) test under instruction. The final step is performed by you getting familiar with testing equipment and protocols and practicing several incline and decline push-ups. This phase will occur at the Biomechanics Research Station (approximately 60 minutes).

3) **Performance Phase**-The following protocol will be used (Approximately 70 minutes):
   - You will be asked to perform push-ups in minimal clothing to allow for accurate assessment of measurements. Males will be asked to perform these push-up variants wearing tight fitting (e.g., biker) shorts, shoes, and no shirt, and females wearing tight fitting (e.g., biker) shorts, shoes, and sports bra. Upon receiving signed consent, video recordings and digital pictures may be taken of your performances of the push-up and other aspects of data collection. If taken, these images may be used for academic or teaching purposes. Refusal to grant permission to record video images will not preclude you from participating in this study.
   - You will perform a workout of the incline and decline push-up. The workout will be divided into five steps, with you performing one body angle each step. There will be three to five minutes break between the steps. The secondary investigator will monitor every phase to help prevent injury.
   - Three orthogonal forces applied to the ground will be simultaneously collected via force platform to assist in the determination of forces that incur at the hand.
   - If you attend a phase at IM Circle during the week while parking is enforced, your parking fee will be reimbursed. Please turn in your receipt for your parking to Keke Yang who will pay you by check.

The compensation for your participation is a check of $ 10. It will be given immediately after you have attempted to complete the study (i.e., no prorated compensation). You are being asked to participate in this study because you are an experienced recreational weight trainer who is familiar with the push-up techniques of interest. Your participation is totally voluntary, and you may choose to participate or not, as well as to discontinue your participation at any time without any explanation and penalty. You may refuse to participate in certain procedures or answer certain questions. The refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. By participating in this study you agree that the materials and data generated (video, pictures, and measurements) may be used for research and academic purposes. You have also been assured that your privacy will be protected to the maximum extent allowable by law. When this research is completed, an abstract of the results will be e-mailed to you. You may also seek personal data for comparison. The data will be stored in the Biomechanics Research Station in the Department of Kinesiology at MSU for a minimum of 3 years after the project has been closed through the Institutional Review Board (IRB). Only the investigators and the IRB will have access to the recorded and coded data that can not be linked to the participants.

This study consists of activities that you use in your regular strength training protocols. Thus, the risk for injury during this study is no different than what would be expected during your regular training. Enough rest time will be assured during the testing phase to lower the chances of a failed attempt. Experienced spotters will monitor every phase to help prevent injury. However, there is always a possibility of injury. Possible injuries include muscle strains and injury to the upper extremities due to the nature of the techniques being used. Though not life threatening, the abraded skin may be discolored for a few days after the testing.

If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or are in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Dr. Eugene Brown at 517-332-1899, email: ewbrown@msu.edu with any questions or to report an injury.

If you have any concerns or questions about this research study, such as scientific issues, how to do any part of it, or to report an injury, please contact Dr. Eugene Brown at 517-332-1899, email: ewbrown@msu.edu or Keke Yang at 517-432-4073, email: yangkeke@msu.edu at the Department of Kinesiology, Michigan State University. If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

Name of participant (Print): ____

By signing below, I voluntarily agree to participate in this research study.

______________________________ ______________________________
Signature Date

______________________________ ______________________________
E-mail Phone

____
Birth Date (month/day/year)

Video Recording Release Consent/Assent Form

Video recordings of you will be taken while you participate in aspects of this research project. Additionally, digital photographs may be taken to document the procedures that were used during the project. If you do so choose to discontinue participation, all data, including video footage, will be destroyed. The informed consent document describes how the video images will be used for this specific study as well as who will have access to the images and where these records will be maintained. The investigators would like your permission to use your video images for academic purposes outside the study. Please use this form to indicate whether you are willing to allow the use of your images for the purposes described below. Your name will not be associated with your images in any case. Upon completion of the study you may request to destroy the video-taping, or erase any photo or portion of the video. Photographs of your participation will be deleted and/or destroyed three years after completion of the study.

Please place a check mark (√) in the boxes to indicate your decision about how your images may be used.

	YES	NO
1. The videos/photos can be shown to other athletes participating in similar projects.	☐	☐
2. The videos/photos can be used for scientific publications and/or presentations.	☐	☐
3. The videos/photos can be shown in non-scientific publications and/or presentations.	☐	☐
4. The videos/photos can be shown in educational settings such as classrooms and conferences.	☐	☐

By signing below, I voluntarily agree to authorize the use of my images.

Name of participant (Print): ____

Signature of Participant: __________________ Date: ___________________

APPLICATION FOR INITIAL REVIEW

APPROVAL OF A PROJECT INVOLVING HUMAN SUBJECTS

Biomedical, Health Sciences Institutional Review Board (BIRB)
Social Science, Behavioral, Education Institutional Review Board (SIRB)
207 Olds Hall, Michigan State University
East Lansing, MI 48824-1047
Phone: (517) 355-2180
Fax: (517) 432-4503
E-mail: irb@msu.edu

Office Hours: M-F (8:00 A.M.-5:00 P.M.)

IRB#: 10-847
APPLICATION ID#: i026685

Title of Project: KINETIC, KINEMATIC, AND ELECTROMYOGRAPHICAL ANALYSIS OF INCLINE AND DECLINE PUSH-UPS WITH DIFFERENT CADENCES

Responsible Project Investigator:	**Eugene W. Brown**		Mailing Address:	**134 IM Sports Circle Building**
Identification Number:	**XXX-XX-8815**		Phone:	**355-4730**
Department:	**KINESIOLOGY**		Fax:	
College:	**EDUCATION**		Email:	**ewbrown@msu.edu**
Academic Rank:	**Associate Professor**			

I accept responsibility for conducting the proposed research in accordance with the protections of human subjects as specified by the IRB, including the supervision of faculty and student co-investigators. There will be adequate resources and facilities to carry out the research.

SIGN HERE: ______________________________

Date: ______________________________

Appendix B

Athropometric Measurement Recording Form, Test-retest Correlations Form, and Calibration Form

Recording Form for Anthropometric Measurements

"Kinetic, Kinematic, and Electromyographical Analysis of Incline and Decline Push-ups with Different Cadences."

Participant Name: ____________________ Date: ____________________

Birth Date (month/day/year): ____

Anthropometric Measurements

Body Weight: ______________________________ kg

Standing Height: ___________________________ cm

Sitting Height: _____________________________ cm

Segment Lengths/Widths

	Length (cm)	**Width (cm)**
Hand	Middle Finger Tip to Wrist Crease	
Wrist		Widest Parts of Wrist Joint
Forearm	Wrist Crease to Elbow Crease	
Elbow		Widest Line across Elbow Crease
Arm	Lateral Epicondyle of Elbow to Greater Tubercle of Humerus	
Bi-acromion Breadth		Right to Left Acromion

Test-retest Correlations Form

Participant		Test 1	Test 2	Test 3
Participant 1	Body Weight (lbs)	172.1	172.2	172.1
	Standing Height (cm)	164.4	164.4	164.3
	Sitting Height (cm)	128.2	128.3	128.1
	Hand Length (in.)	18.6	18.6	18.6
	Forearm Length (in.)	26.3	26.4	26.4
	Arm Length (in.)	26.6	26.6	26.6
	Wrist Width (in.)	6.1	6.0	6.1
	Elbow Width (in.)	9.4	9.5	9.3
	Bi-acromion breadth (in.)	18.1	18.2	18.1
Participant 2	Body Weight (lbs)	143.5	143.5	143.5
	Standing Height (cm)	176.8	176.9	176.8
	Sitting Height (cm)	130.5	130.5	130.6
	Hand Length (in.)	19.0	19.0	19.1
	Forearm Length (in.)	26.9	26.8	26.8
	Arm Length (in.)	30.6	30.6	30.5
	Wrist Width (in.)	6.1	6.1	6.1
	Elbow Width (in.)	9.8	9.9	9.7
	Bi-acromion breadth (in.)	16.5	16.3	16.3
Participant 3	Body Weight (lbs)	133.3	133.2	133.2
	Standing Height (cm)	165.0	165.1	159.8
	Sitting Height (cm)	134.0	134.1	134.0

	Hand Length (in.)	18.6	18.6	18.6
	Forearm Length (in.)	25.1	25.1	25.3
	Arm Length (in.)	26.1	26.1	26.1
	Wrist Width (in.)	6.2	6.2	6.3
	Elbow Width (in.)	9.2	9.2	9.1
	Bi-acromion breadth (in.)	18.2	18.3	18.0
Participant 4	Body Weight (lbs)	169.5	169.5	169.5
	Standing Height (cm)	182.7	182.9	182.8
	Sitting Height (cm)	137.6	137.6	137.4
	Hand Length (in.)	19.5	19.6	19.
	Forearm Length (in.)	27.0	27.1	27.1
	Arm Length (in.)	32.1	32.1	32.1
	Wrist Width (in.)	6.3	6.4	6.3
	Elbow Width (in.)	8.6	8.7	8.6
	Bi-acromion breadth (in.)	17.2	17.2	17.6
Participant 5	Body Weight (lbs)	142.9	142.8	142.7
	Standing Height (cm)	171.8	171.8	171.6
	Sitting Height (cm)	134.7	134.7	134.8
	Hand Length (in.)	18.4	18.6	18.4
	Forearm Length (in.)	25.3	25.3	25.3
	Arm Length (in.)	29.0	29.1	29.3
	Wrist Width (in.)	5.8	5.7	5.7
	Elbow Width (in.)	8.9	8.9	9.1
	Bi-acromion breadth (in.)	18.6	18.7	18.6

Calibration Form for 0^0, $30^{0,}$ and 45^0 Force Platform

		0 lb	30lbs	60blbs	90lbs	120lbs	150lbs
Fx (lbs)	**0^0**	0.00	0.00	0.00	0.00	0.00	0.00
	30^0	0.12	15.33	30.16	45.21	60.45	75.48
	45^0	0.16	21.30	42.58	63.67	85.22	106.59
Fy (lbs)	**0^0**	0.00	0.00	0.00	0.00	0.00	0.00
	30^0	0.03	0.05	0.05	0.02	0.06	0.07
	45^0	0.05	0.05	0.04	0.04	0.06	0.6
Fz (lbs)	**0^0**	0.00	30.08	60.13	89.97	120.11	150.02
	30^0	0.28	26.09	52.33	78.25	104.41	130.53
	45^0	0.34	21.22	42.63	63.89	85.31	106.23

APPENDIX C

Questionnaires

Questionnaire 1

History of Participants

This study requires participants to perform incline and decline push-ups with different cadences and body angles. The performance of these push-ups will be very similar to the techniques that are used in the strength training practices. Therefore, the risk of injury during this study should be the same as during your normal strength training. However, all strength training exercises have some inherent risk of injury that increases if other injuries are present. This questionnaire will be used to determine if you have any contraindications that should exclude you from participation in this study.

Name of participant (Print): ______________________________________

Circle the responses which best fits your situation.

1. Are you currently performing incline or decline push-ups in your strength training program? YES NO

   If NO:

   Have you ever performed incline or decline push-ups in your strength training program? YES NO

2. Which one best describes your past experience with incline or decline push-ups?

   No experience (never did incline or decline push-ups) YES

   Little experience (did incline or decline push-ups for 0-1 month) YES

   Moderate experience (did incline or decline push-ups for 1-6 months) YES

   Much experience (did incline or decline push-ups for over 6 months) YES

Signature ______________________ Date ______________________

Questionnaire 2

Medical Information

This study requires participants to perform the incline and decline push-up with different cadences and body angles. The performance of these push-ups will be very similar to the techniques that are used in strength training practices. Therefore, the risk of injury during this study should be the same as during normal strength training. However, all strength training exercises have some inherent risk of injury that increases if other injuries are present. This questionnaire will be used to determine if you have any contraindications that should exclude you from participation in this study.

1. Have you had a physician in the last year clearing you to train and participate in exercises?

(a) YES (I had a physician) NO (I did not have a physician) If yes, go to (b)

(b) YES (clearing) NO (not clearing)

If NO, please explain:

2. Are you currently under a physician's/coach's/ athletic trainer's orders to not perform the push-up and/or upper body exercises in a strength training program?

YES NO

If YES, please explain:

3. Have you ever been under a physician's/coach's/athletic trainer's orders to not perform the push-up and/or upper body exercises?

YES NO

If YES, please explain when you were allowed to start training again:

4. Have you had any of the following injuries? If YES, please circle which of the following have occurred and indicate how long ago these injuries occurred.

	Yes or No	When did the injury occur (month/year)
Sprain or strain that affects the wrist joint	**Yes or No**	
Sprain or strain that affects the elbow joint	**Yes or No**	
Injured shoulders	**Yes or No**	
Injury to the spine	**Yes or No**	
Broken bone of the upper extremity	**Yes or No**	
Injuries to the hip/thigh/knee/ankle/foot	**Yes or No**	
Any other injury that you feel may affect your ability to perform incline and decline push-ups?	**Yes or No**	

This information is accurate to the best of my knowledge.

Name of participant (Print): ____

______________________________ ______________________________
Signature Date

Questionnaire #3

Pre-Testing Information

Name of participant (Print): ____

1. How many hours of sleep did you have last night? _____________________

Circle the responses which best fits your situation.

2. Have you engaged in any of the following activities in the last 48 hours?

   a. Weight training of the upper extremities and trunk? YES NO

   b. A competitive sporting event such as basketball, baseball, football that lasted more than 20 minutes? YES NO

   c. An upper extremity endurance activity such as swimming, tennis, or badminton that lasted more than 20 minutes? YES NO

3. Do you have any pains or illnesses today that would prevent you from completing today's testing or could possibly keep you from performing at your optimal level?

   YES NO

   If YES, please explain:

______________________________ ______________________________

Signature Date

APPENDIX D

Advertisement

Push-up Participants Needed!

The project of “Analysis of Incline and Decline Push-ups with Different Cadences” is looking for participants between 18-70 years old. The compensation for participation is $10. Each participant’s involvement in this project will last about 2 hours in the Department of Kinesiology at Michigan State University.

Participants will be requested to perform totally 45 push-ups at 3 paces (with a break between sets of 3 push-ups). Motion data, which are collected via non-invasive means, will be gathered during the activity.

Any people who are interested and free from injuries that may adversely affect their performance of the push-up exercise can apply to participate!

If interested please contact:

Keke Yang, Doctoral Student
Cell: 517-775-3464
E-mail: yangkeke@msu.edu

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