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# Analysis of Push-Up and Pull-Up Variants to Develop an Upper Extremity Model

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Analysis of Push-Up and Pull-Up Variants to Develop an Upper Extremity Model

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THESIS

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A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Education
at the University of Kentucky

By

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ABSTRACT OF THESIS

Analysis of Push-Up and Pull-Up Variants to Develop an Upper Extremity Model

Musculoskeletal Injuries are the most common cause of severe long-term pain and physical disability. Push-Ups and Pull-Ups are effective dynamic exercises that mimic high level function activities, such as those used in the military. The model developed allows for researchers to analyze the forces and moments associated with the shoulder, elbow and wrist, to further assess function in military personnel, athletes and the active population. The model also follows the guidelines set forth by the International Society of Biomechanics (ISB).

KEYWORDS: [Musculoskeletal, shoulder, upper extremity, model, force, moment]

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07/25/2019

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# CHAPTER 1. INTRODUCTION

## 1.1 Introduction

Musculoskeletal injuries are the most common cause of severe long-term pain and physical disability. (Abt et al, 2014) The incidence rate of musculoskeletal injuries among Special Operations Forces (SOF) has proven to impede physical readiness, limit active duty days and possess a financial burden. Over the period of one year, SOF reported an incidence rate for upper extremity injuries at 34.6%. Of those injuries, 30.0% of them were reported to be preventable. (Abt et al, 2014) These injuries result in time lost from work and training which hinders the success of our military units. Additionally, those who sustain an injury to the shoulder are at risk for long term disability and pain. More research is needed to identify better evidence for rehabilitation post-shoulder injury that improves outcomes and minimizes long-term deficits in the military.

The muscles surrounding the glenohumeral joint provide dynamic stability to the shoulder complex. These muscles must be able to maintain adequate force and coordination in order to provide stability to the joint during demanding exercises and activity. Understanding the properties of force, coupled with the anatomy of the GH joint will allow researchers to better predict joint forces as well as moments. While the muscles and ligaments provide support to the shoulder, the bony makeup makes it prone to instability. The shoulder moves in multiple directions making it the most mobile joint in the body. High functioning military members are at a high risk for anterior shoulder instability due to an intense, physical environment. (Kardouni at al, 2016) Superior Labrum Anterior-Posterior (SLAP) tears represent a significant source of shoulder disability in the highly active population, happening from acute injuries, such as dislocations, and can occur from overuse during repetitive activities. (Neuman, 2010) The success of the rehab is significantly determined by return to play, which is dependent on the ability to restore the function of the muscles and structures surrounding the joint. (Kama and Clasper, 2005)

Biomechanics is a subset of Kinesiology that focuses on the mechanical movements of living things. As a field that studies force and motion, it is a crucial puzzle piece to developing solutions that will assist injured patients in returning to work, sport or physical activity. Daily, the field of biomechanics evolves to produce necessary evidence to support the theories laid out by researchers.. Biomechanics as a discipline has made great strides in the scientific community. Within the research of biomechanics, we have a few factors that play roles in laboratory discoveries in addition to the men and women working in the field. Tools that are used to analyze data and generate it are mathematical modeling and the equipment. Without those tools we wouldn’t be where we are today in the field. As researchers, it’s our job to look at the bigger picture and ask why are these discoveries that we are making in the lab so important. We make these discoveries to develop good clinical practice to improve our patient treatment and outcomes, the ultimate goal.

There is no validated shoulder model for kinetic characteristics during high level function activities such as push-ups or pull-ups, common exercises for the military and physically active individuals. Without this validated model, there is no evidence to support what can be termed “normal”. Since there is no model to determine the forces and moments, the clinician is limited on how to assess and validate their rehabilitation techniques. Therefore, the primary purpose of this study is to develop an upper extremity biomechanical model to provide a framework for calculating the forces and moments at the shoulder, elbow and wrist. The biomechanical model will provide a powerful tool for analyzing changes in the shoulder, elbow and wrist during different progressive pull-ups and push-up exercises. To improve the rehabilitation of an individual, forces and moments need to be identified to accurately develop a validated progression return protocol. Designing this model will allow clinicians and researchers alike to determine how modifications of clinical exercises affect the shoulder loading at different positions. Future research can investigate different strategies to enhance function through evidence-based progression.

# CHAPTER 2. METHODS

## 2.1 Subjects

Ten consenting subjects between the ages of 18 and 45 volunteered to participate in the push-up component of the study. Potential subjects who reported an upper extremity injury or surgery within the past 2 years were excluded. Participants were asked to complete a data collection form which included simple demographic information such as age, race, height and weight. In addition, they were to fill out an activity scale specific to the upper extremity and a shoulder function scale called the PENN Shoulder Score. For the push-up component, the subjects were required to be able to complete at least five push-ups based on USMC standards (Push-up: elbows bent to at least 90 degrees in the downward position.) The time in lab for each subject lasted approximately 3 hours.

One subject completed the pull-up portion of the study following the same exclusion criteria, data collection form and activity/function scale. The subject was required to complete at least five pull-ups following the USMC standards (pull-up: chin above or equal to bar height in the upward position) The time in lab also lasted approximately 3 hours.

## 2.2 Activities

### 2.2.1 Push-Up component:

The following push-up variants were performed by each subject in the push-up portion of the study. Before beginning the sets, 1 to 3 reps were allowed to allow the subject to become familiar with the instrumentation and tasks. They were performed in a randomized order, 5 repetitions each in accordance to a metronome beat equal to 60 bpm. A minimum of 3 minutes was given between variants to allow the effects of fatigue to be minuscule.

<u>Standard push-up:</u> A standard push-up is performed with both hands and feet in contact with the floor. Hands will be aligned under the shoulders at a distance corresponding to acromion width.

Modified/Knee push-up: Modified push-ups are performed with the knees on the ground. Hands will be placed directly in line with the shoulders with both hands and knees in contact with the floor.

Wide push-up: A wide push-up will require hands to be placed wider than shoulder width with both hands and feet in contact with the floor. The subject's hands will be 150% of the distance apart than in the standard push up.

Narrow push-up: A narrow push-up requires hands to be less than shoulder width apart and perform a full push up with both hands and feet in contact with the floor. The subject's hands will be together with thumbs and index fingers touching and placed directly below the sternum.

### 2.2.2 Pull-Up Component

Before beginning, the subjects were allowed 1 to 3 reps for familiarization. The subject performing the pull-ups performed each variant in a random order, with 5 repetitions each at 60 bpm. As with the push-ups, a minimum of 3 minutes was required between variants to minimize fatigue.

Dead-hangs: Dead-hangs require the person to simply hang from the pull-up bar for a pre-determined amount of time. Starting point for this exercise is hold the position for a minimum of 15 seconds. This is a static hold exercise that occurs at 0% of a pull-up.

Full pull-up pronated: A pull-up beings in a dead-hang position with a pronated grip. Knees are allowed to have a slight bend while pulling-up to the bar. Once the chin clears the bar, the body can be slowly lowered back to the dead-hang position. This exercise begins at 0% of a pull-up, working through both the concentric and eccentric phase, and ends at 100%.

Full pull-up supinated: A pull-up beings in a dead-hang position with a supinated grip. Knees are allowed to have a slight bend while pulling-up to the bar. Once the chin clears the bar, the body can be slowly lowered back to the dead-hang position. This exercise begins at 0% of a pull-up, working through both the concentric and eccentric phase, and ends at 100%.

L-Sits: The subject will hold the pull-up bar in the same position and technique as the dead hang. They will then lift their legs in front of them until their hips are flexed to a right angle with their knees extended as far as possible. They will hold this position for 2 seconds and lower their legs. They will repeat this 5 times.

Assisted Pull-Ups: This exercise uses an unweighted device to reduce the load that needs to be lifted each session. A heavy-duty elastic band specifically designed for this exercise will support the lower leg on the instrumented side to assist the subject to raise their chin to the bar. They will repeat this 5 times.

## 2.3 Protocol

Motion data was captured using a three-dimensional motion capture system. Participants were equipped with forty one retroreflective markers attached to the skin with double-sided tape. Nexus Motion Capture Software was used to record time synchronized marker trajectory, pull-up bar force, push-up force, and muscle activity data. Motion and force data were reconstructed, filtered, and analyzed using Visual 3D. A pull-up bar (specifically made by the University of Kentucky Department of Engineering) instrumented with two force sensors (ATI) with adjustable grip locations was used to measure kinetics. The bar provides a reaction force vector that will allow us to calculate the force on the shoulder during each pull-up exercise. A Bertec Force Plate was used to capture the ground reaction force during the push-up component that will also allow us to calculate the force on the shoulder during the push-ups.

## 2.4 Model

**Shoulder: Origin (Glenohumeral (GH) center; midpoint between right anterior shoulder (RASH) and right posterior shoulder (RPSH).**

X – Anterior line to the GH center

Y – Vertical line perpendicular to the GH center

Z – Lateral line pointing left of the GH center (in respect to the left shoulder)

**Elbow: Origin (Midpoint between Right lateral epicondyle (RLEL) and Right medial epicondyle (RMEL)**

X - Midpoint between RLEL and RMEL following the forearm

Y - Midpoint between RLEL and RMEL following the humerus

Z – Midpoint between RLEL and RMEL vertical line perpendicular to line in the X direction

**Wrist: Origin (Midpoint between right radial styloid process (RRSP) and right ulnar styloid process (RUSP)**

X – Vertical line pointing up from the midpoint between RRSP and RUSP

Y – Midpoint between RRSP and RUSP following the forearm

Z – Lateral line starting at the midpoint between RRSP and RUSP pointing left

(Wu et al, 2005)

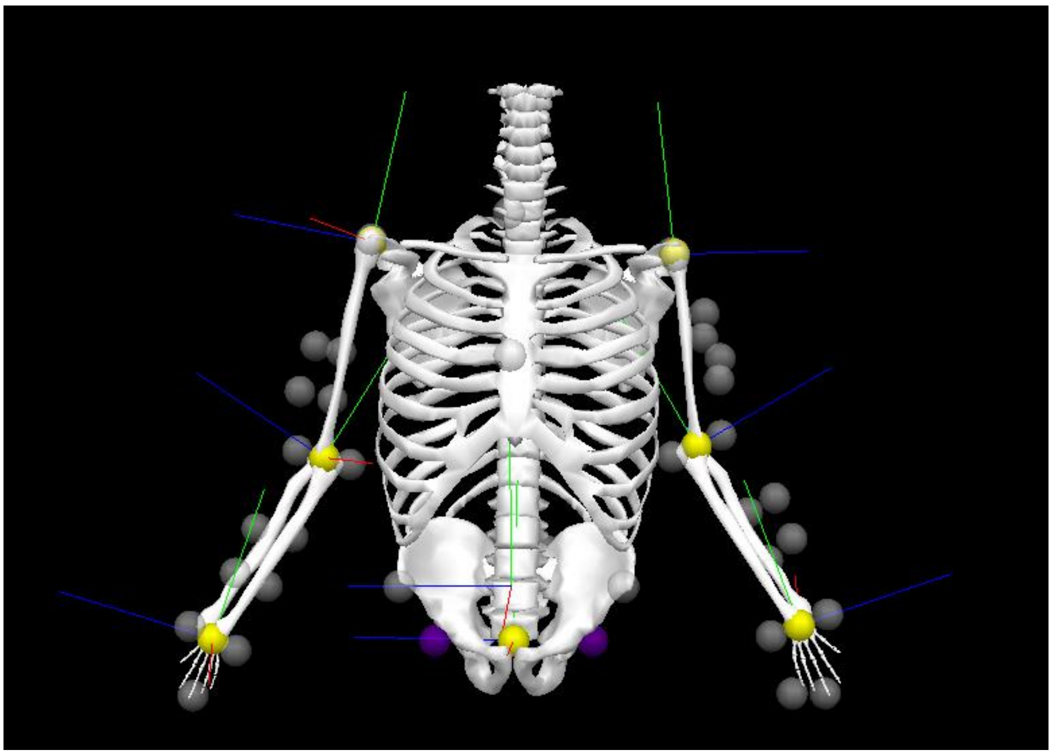

Figure 1.1: This figure represents the model in Visual 3D with directions at each joint. Red-X Green-Y Blue- Z

## 2.5 Visual 3D Model:

Table 1.1: Forces

| **Force (+)** | | **Force (-)** | | **Direction** |
|---|---|---|---|---|
| Distraction (+) | Upward rotation in sagittal plane | Compression (-) | Downward rotation in sagittal plane | Z (Sagittal) |
| Anterior (+) | Downward rotation in frontal plane | Posterior (-) | Upward rotation in frontal plane | X (Frontal) |
| Superior (+) | Counter-clockwise rotation in ransverse plane | Inferior (-) | Clockwise rotation in transverse plane | Y (Transverse) |

Table 2.1: Moments

| **Moment (+)** | | **Moment (-)** | | **Direction** |
|---|---|---|---|---|
| Flexion (+) | Upward rotation in sagittal plane | Extension (-) | Downward rotation in sagittal plane | Z (Sagittal) |
| Adduction (+) | Downward rotation in frontal plane | Abduction (-) | Upward rotation in frontal plane | X (Frontal) |
| Internal (+) | Counterclockwise rotation | External (-) | Clockwise rotation | Y (Transverse) |

# CHAPTER 3. RESULTS

## 3.1 Results

The following tables represent the maximum data of the forces and moments that were extracted from the model based on one individual. All data were based on task percent. No statistical tests were performed as this is intended to be for reference use for future researchers. Additional tests will be performed at a later date to acquire comparable data.

Table 3.1: Pull-Up Shoulder Forces- Max (N/Kg)

| | X | Y | Z |
|---|---|---|---|
| Pronated | 3.365071 | 7.054762 | 0.351014 |
| Supinated | 0.329204 | 0.802991 | 0.208357 |
| Assisted | 2.994638 | 5.702473 | 1.759225 |
| Hang | 0.273047 | 0.484457 | 0.294717 |
| Lsit | 0.208584 | 2.197152 | 0.257164 |

Table 4.1: Pull-Up Shoulder Moments- Max (Nm/Kg)

| | X | Y | Z |
|---|---|---|---|
| Pronated | 6.484258 | 6.234424 | 3.219257 |
| Supinated | 0.016311 | 0.008902 | 0.179033 |
| Assisted | 5.773884 | 6.453260 | 5.025716 |
| Hang | 0.013368 | 0.006694 | 0.093524 |
| Lsit | 0.060249 | 0.012089 | 0.144280 |

Table 5.1: Push-Up Shoulder Forces- Max (N/Kg)

| | X | Y | Z |
|---|---|---|---|
| Modified | -0.382303 | 0.232578 | 0.260579 |
| Narrow | -0.402795 | 0.163984 | 0.246001 |
| Regular | -0.402036 | 0.175801 | 0.294591 |
| Wide | -0.396564 | 0.251180 | 0.238062 |

Table 6.1: Push-Up Shoulder Moments- Max (Nm/Kg)

| | X | Y | Z |
|---|---|---|---|
| Modified | 0.020462 | 0.008804 | 0.015538 |
| Narrow | 0.023747 | 0.013566 | 0.014652 |
| Regular | 0.019374 | 0.007965 | 0.004243 |
| Wide | 0.008951 | 0.006335 | 0.001044 |

# CHAPTER 4. DISCUSSION

## 4.1 Discussion

Although this is the first of its kind for the shoulder, we do know that kinetic analyses of the lower extremity have been validated and used in research to aid in injury prevention and rehabilitation. Yin et al in 2015 used kinetic analysis to assess the landing phase of a jumping task to better develop rehabilitation in ACL injuries patients. Murray and Johnson in 2004 developed a set of external forces and moments at the shoulder from everyday tasks using inverse dynamics. Although they did not comment on internal forces and moments, using their data and processing it with the model developed in this project could allow researchers to validate the model being proposed in this situation. This could be a next step in the process of producing reliable data to follow through with developing a progressive return protocol for shoulder injuries.

A number of limitations were incurred during this study. Those include; a small sample size, new instrumentation and method to determining force at the shoulder joint, as well as a new model based on ISB recommendations. Determining the joint center in the shoulder also proved difficult. The model only calculates the joint center by determining the center from two points, the anterior and posterior shoulder markers. To better determine the center, a functional test, similar to the "star" test on the hip, could be implemented. This could aid in more precise data.

# CHAPTER 5. CONCLUSION

## 5.1 Conclusion

By developing this upper extremity biomechanical model, we are now able to calculate the internal forces and moments at the shoulder joint as well as the elbow and wrist. Future research can investigate different strategies to enhance function through evidence-based progression. This biomechanical model will allow future clinicians and researchers to keep investigating to create better rehabilitation guidelines for higher function activities such as those needed in the military

BIBLIOGRAPHY

1. Abt JP, Sell TC, Lovalekar MT, et al. Injury epidemiology of U.S. Army Special Operations forces. Mil Med. 2014;179(10):1106-1112

2. Anthony D.Woolf & Bruce Pfleger. Burden of major musculoskeletal conditions. Bulletin of the World Health Organization. 2003, 81 (9)646-656.

3. Antosh J Ivan, Tokish M John, Owens D Brett. 2016. Posterior Shoulder Instability: Current Surgical Management. Sports Health. 1-7. Doi: 10.1177/1941738116672446

4. Kama, RJ, Clasper, J. Incidence of SLAP lesions in Military Populations. J R Army Med Corps 2005; 151: 171-175

5. KARDOUNI, J. R., C. J. MCKINNON, and A. L. SEITZ. Incidence of Shoulder Dislocations and the Rate of Recurrent Instability in Soldiers. Med. Sci. Sports Exerc., Vol. 48, No. 11, pp. 2150–2156, 2016.

6. Kaufman R Kenton, Brodine Stephanie, Shaffer Richard. Military Trainging Related injuries: Survalience, Research, Prevention. Am J Prev Med. 2000;18(3S):54–63

7. Hauret et al. Musculoskeletal Injuries. Am J Prev Med. 2010;38(1S):S61–S70

8. Murray, Ingram and Johnson, Garth. A study of the external forces and moments at the shoulder and elbow while performing everyday tasks. Clinical Biomechanics. Vol. 19, No. 6, pp 586-594, 2004.

9. Rossy William, Sancehez George, Sanchez Anthony, Provencher T Matthew. Superior Labral Anterior-Posterior (SLAP) Tears in the Military: A Clinincal Review of Incidence, Diagnosis, and Treatment Compared wit hthe Civilian Population. Sports Health. 2016, 1-4 DOI: 10.1177/1941738116671693

10. Savio L-Y, Woo. Contribution of Biomechanics to Clinical Practice in Orthopaedics. 2004.

11. Waterman Brian, Owens D Brett, Tokish M John. Anterior Shoulder Instability in the Military Athlete. Sports health. 2016, 1-6. DOI: 10.1177/1941738116672161

12. University of Kentucky, "University of Kentucky Thesis Template" (2018). *UKnowledge Documents and Forms*. 10. https://uknowledge.uky.edu/uknowledge_docs/10

13. Wu Ge and Cavanagh R. Peter. ISB Recommendations for the Standardization in the Reporting of Kinematic Data. J. Biomechanics, Vol. 28, No. 10. pp. 1257-1261, 1995.

14. Wu et al, ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion. Part 2: shoulder, elbow, wrist and hand. Journal of Biomechanics 38 (2005) 981–992. doi:10.1016/j.jbiomech.2004.05.042

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