Knee and Ankle Biomechanics during Squatting with Heels on and off the Ground, with and without weight shifting

Jonathan Fox, MS. and Mohamed Samir Hefzy, Ph.D., P.E.

Biomechanics and Assistive Technology Laboratory,
Departments of Bioengineering and Mechanical Engineering, The University of Toledo, Toledo, Ohio

Introduction

- Squatting is a regular daily activity.
  - It is used in sports, work, gardening, leisure, floor activities, resting, and others
- Different postures can be used such as:
  - Asian Squat: Heels on the ground
  - Catcher's Squat: Heels off the ground

Asian Squat

Catcher's Squat

- Body weight shifting:
  - For long periods of squatting it is common for someone to shift their weight from one leg to the other in order to maintain comfort

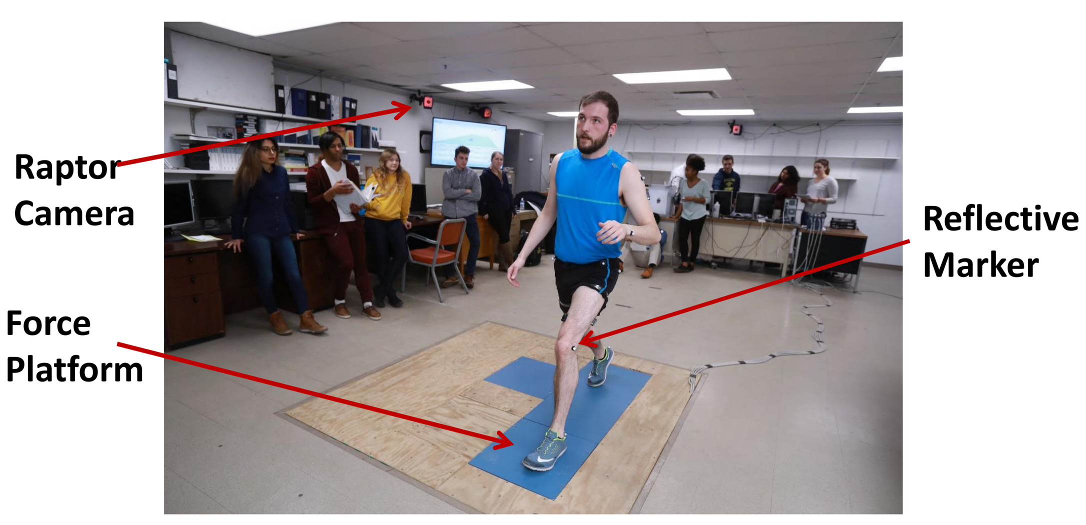
Asian Squat Clinic, HI PERFORMANCE CENTER, https://www.youtube.com/watch?v=zrAU0ACGLEo

Objectives

- The purpose of this study was to examine the biomechanics of the knee and ankle joints during Asian and Catcher's Squats.
- The effect of weight shifting was also examined.
- This study also looked at the associated muscle activities.

Experimental Setup

- The figure below shows the experimental set-up.
- Ten Raptor-E digital cameras [1] from Motion Analysis, Inc. were used to capture the motion data at 120 Hz.
- Optima digital force platforms from Advanced Mechanical Technology, Inc. were use in conjunction with the cameras to collect ground reaction force data at 720 Hz.
- Reflective markers were placed on the surface of the skin in order to identify key landmarks of the body for motion analysis.
- Trigno EMG sensors from Delsys, Inc. were used to capture the muscle activity during squatting at 720 Hz.
- Cortex software from Motion Analysis, Inc. [2] was used to simultaneously collect the motion data from the cameras, the ground reaction forces from the force platforms, and the voltage data from the EMG sensors.



Experimental set-up

Experimental Procedure

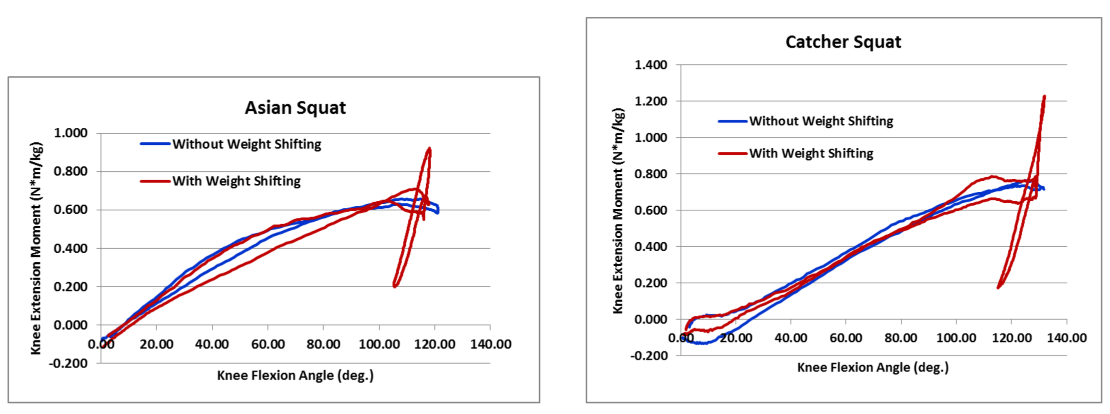
- Four male volunteers and four female volunteers were recruited from the student population at the University of Toledo.
- The testing protocol was approved by the Institutional Review Board at the University of Toledo (IRB # 107636).
- Ten EMG sensors were placed on the rectus femoris, the biceps femoris, the tibialis anterior, and the lateral and medial heads of the gastrocnemius on both the right and left legs as described by Basmajian and Blumenstein [3].
- Once the EMG sensors were placed over the muscles, a series of maximum voluntary contraction (MVC) tests were done.
- The volunteers were then instrumented with 21 reflective markers according to the Helen-Hayes model [4].
- The volunteers performed the Asian and the Catcher's squats by squatting down as far as they could, and would then rise.
- The volunteers would repeat the Asian and Catcher's squats with the addition of weight shifting. After squatting down as far as they could, they shifted their weight onto their right leg, and then onto their left leg. They would then return to a neutral position and then stand.

Data processing:

- The data from the markers were used to calculate the joint centers based on the anthropometric data within the Cortex software [2].
- The KinTools RT toolset within Cortex software was used to calculate joint angles and moments from the markers and force platform data.
- The EMG data were imported into EMGworks software [5] from Delsys® Inc.
- The EMG data were normalized w.r.t. the individual muscles' average maximum voluntary contraction

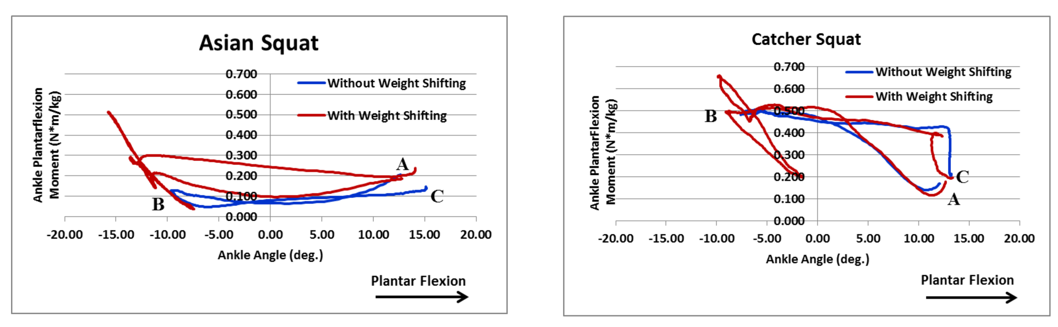
Results

Knee Extension Moments



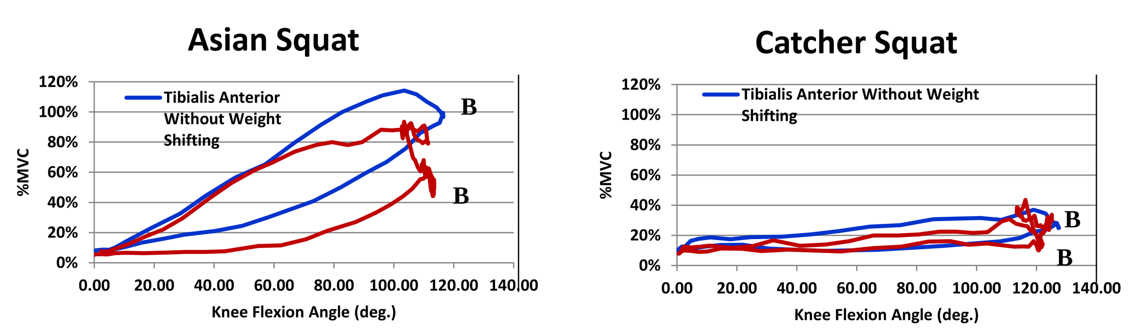
- Catcher's squats have greater knee extension moments
- Catcher's squats have slightly greater knee flexion angles
- Shifting weight caused the knee extension moments to increase

Ankle Plantar Flexion Moments

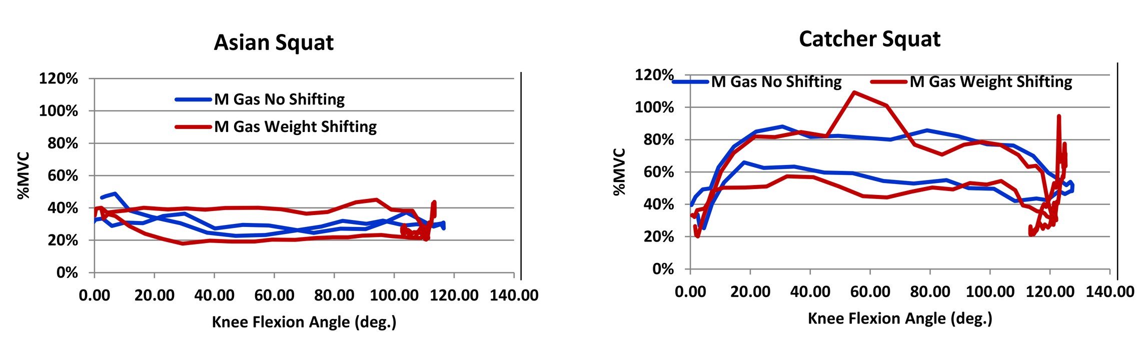


- Catcher's squats have greater ankle plantar flexion moments
- Asian squats have slightly greater plantar and dorsi-flexion angles
- Shifting weight caused the ankle plantar flexion moments to significantly increase

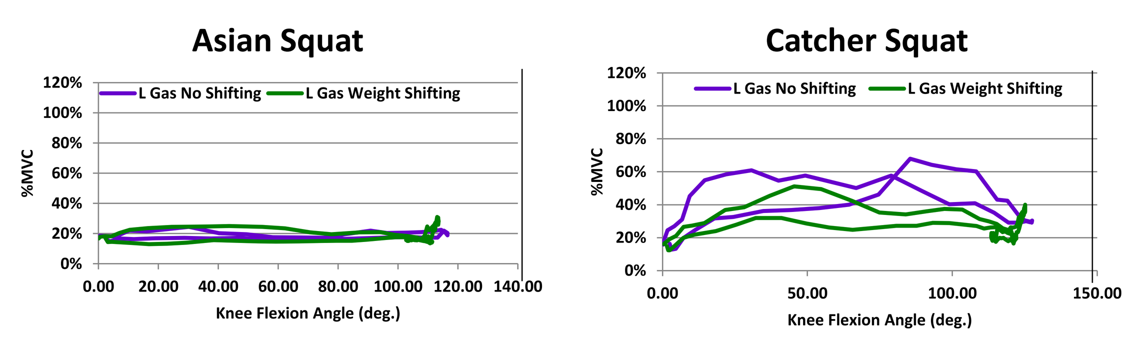
Tibialis Anterior Muscle Activities



Medial Gastrocnemius Muscle Activities

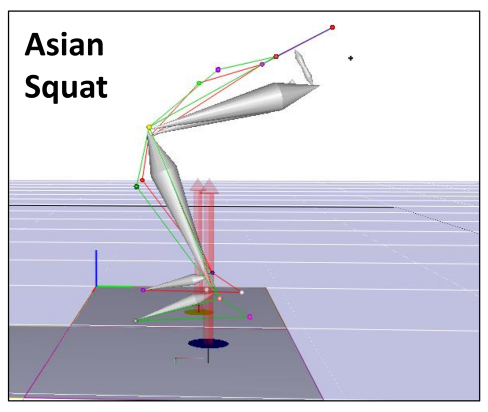


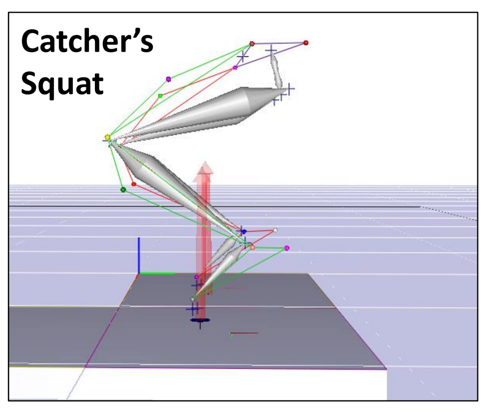
Lateral Gastrocnemius Muscle Activities



- Tibialis anterior muscle activities during the Catcher's squat were smaller than those during the Asian squat.
- Medial and lateral gastrocnemius activities were larger in the Catcher's squat than during the Asian squat.

Discussion





- During the Catcher's squat:
  - Heels are lifted off the ground and Center of pressure moves anteriorly
  - Knee joint moves anteriorly

    This will cause an increase in the moment arm of the ground reaction force around the knee joint, thus producing larger knee extension moments.
  - Ankle joint moves more proximally

    This will cause an increase in the moment arm of the ground reaction force around the ankle joint, thus producing larger ankle plantar flexion moments.

Conclusions

- Catcher's squats have larger knee extension and ankle plantar flexion moments. EMG data consistently show that the tibialis anterior muscle activities were smaller and the medial and lateral gastrocnemius muscle activities were larger in the catcher's squats.
- Shifting weight caused the knee extension moments and ankle plantar flexion moments to increase during both Asian and catcher's squats.
- The Catcher's squat caused a greater increase in the knee extension moment when weight shifting occurred. Therefore, it is recommended that the Asian squat be considered when squatting for extended periods of time.
- Weight shifting should be avoided if possible, and should instead be replaced with standing.

References

[1] https://www.motionanalysis.com/system/raptor-e/ [2] https://www.motionanalysis.com/cortex/
[3] Basmajian, J.V. and Blumenstein, R., Electrode Placement in EMG Biofeedback, 1980, Baltimore: Williams and Wilkins.
[4] Davis III, R.B., Ounpuu, S., Tyburski, D., and gage, J.R., A gait analysis data collection and reduction technique. Human Movement Science 10 (1991), pp. 575-587.
[5] http://www.delsys.com/product/emgworks-software/