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Title: Three-Dimensional Kinematic Characterization of An Object Pick-up Task Using Motion Capture

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Author Questionnaire

1. We have marked your project as author-provided footage, meaning you film the video yourself and provide JoVE with the footage to edit. JoVE will not send the videographer. Please confirm that this is correct.

✓ Correct

2. Interview statements: Which interview statement filming option is the most appropriate for your group? **Please select one.**

☒ Interviewees self-record interview statements. JoVE can provide support for this option.

3. Proposed interview filming date: Please indicate the proposed date that your group will self-film interviews: **MM/DD/YYYY**

When you are ready to submit your video files, please contact our Content Manager, [Utkarsh Khare](#).

Current Protocol Length

Number of Steps: 40

Number of Shots: 62

Interviews

INTRODUCTION:

REQUIRED: Summarize your research focus and the main questions it aims to answer.

- 1.1. **Arun Perumal:** In this study, we aim to decode the object pick-up task using motion capture and provide a detailed description of its kinematic elements.
 - 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Suggested B roll: 5.6.1.*

~~Describe the research gap or limitation in existing methods and how this protocol addresses them.~~

- 1.2. **Arun Perumal:** Existing methods lack a clear understanding of task performance under normal conditions. This protocol establishes baseline performance, improving interpretation and clinical applicability.
 - 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

CONCLUSION:

~~What does this protocol allow researchers to study or measure?~~

- 1.3. **Arun Perumal:** This protocol allows researchers to quantify and characterize distinct movement strategies used during an object pick-up task, including squat-dominant, hinge-dominant, and hybrid patterns.
 - 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Suggested B roll: 5.7.1*

~~Are there any additional methods or analyses that can be performed following this procedure?~~

- 1.4. **Arun Perumal:** Additional analyses that can be performed following this procedure include joint velocities, center-of-mass dynamics, and ground reaction forces, providing a more comprehensive understanding of task performance.

- 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

- 1.5. **Arun Perumal:** Future research can expand on our motion capture protocol to examine compensatory mechanisms, particularly in conditions related to musculoskeletal diseases.

- 1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Ethics Title Card

This study has been approved by the Institutional Review Board (IRB) at Nanyang Technological University. All participants provided written informed consent prior to participation

Protocol

Video editor: Please blur the face of the participant

2. Participant Screening and Safety Check

Demonstrators: Celest Yee Suan So and Pablo Cruz Gonzalez

- 2.1. To begin, ask the participant to wear a singlet and lightweight shorts. Ensure that the participant is barefoot [1].

- 2.1.1. LAB MEDIA: IMG_0014.MOV: 00:03-00:15

- 2.2. Instruct the participant to walk a short distance away from the examiner at a comfortable self-selected pace [1]. Then, ask the participant to turn and walk back toward the examiner at the same pace [2].

- 2.2.1. LAB MEDIA: IMG_0014.MOV: 00:25-00:36

- 2.2.2. LAB MEDIA: IMG_0014.MOV: 00:36-00:42

- 2.3. Guide the participant to extend the neck by looking upward, flex the neck by looking downward, rotate the head to the left and right, and tilt the head to both sides [1].

- 2.3.1. LAB MEDIA: IMG_0014.MOV: 00:48-01:20

- 2.4. Instruct the participant to bend the body forward and backward, rotate the body to the left and right, and perform side bending to both sides [1]. Once all movements are completed comfortably and safely, instruct the participant to remain standing for subsequent marker placement [2].

- 2.4.1. LAB MEDIA: IMG_0014.MOV: 01:20-01:48

- 2.4.2. LAB MEDIA: IMG_0014.MOV: 01:48-01:55

- 2.5. Ensure the participant is standing in a relaxed, upright posture with arms resting naturally by the sides [1].

- 2.5.1. LAB MEDIA: IMG_0014.MOV: 01:56-02:06.

3. Full-Body Marker Placement

- 3.1. Palpate the posterior anatomical landmarks [1] and place magnetic bases sequentially over the T4 [2], T8 [3], T10 spinous process [4], and left and right posterior superior iliac spine [5].

- 3.1.1. LAB MEDIA: IMG_0014.MOV: 02:16-02:19

- 3.1.2. LAB MEDIA: IMG_0014.MOV: 02:23-02:26

- 3.1.3. LAB MEDIA: IMG_0014.MOV: 02:34-02:42

- 3.1.4. LAB MEDIA: IMG_0014.MOV: 02:46-02:54

- 3.1.5. LAB MEDIA: IMG_0014.MOV: 03:05-03:12
- 3.2. Next, place a magnetic base over the posterior surface of the iliac crest, approximately 2 to 3 inches superolateral to the posterior superior iliac spine [1]. Once the posterior magnetic bases are positioned, secure them with tape [2].
 - 3.2.1. LAB MEDIA: IMG_0014.MOV: 03:12-03:28
 - 3.2.2. LAB MEDIA: IMG_0014.MOV: 03:51-04:02
- 3.3. Then, ask the participant to turn and face the examiner while standing upright [1].
 - 3.3.1. LAB MEDIA: IMG_0014.MOV: 04:02-04:06
- 3.4. Palpate the left and right anterior superior iliac spines and secure a magnetic base over this landmark [1]. Locate the xiphoid process and place a magnetic base over it [2]. Then, secure the anterior magnetic bases with tape [3].
 - 3.4.1. LAB MEDIA: IMG_0014.MOV: 04:15 – 04:36
 - 3.4.2. LAB MEDIA: IMG_0014.MOV: 05:08 – 05:16
 - 3.4.3. LAB MEDIA: IMG_0014.MOV: 05:23 – 05:29
- 3.5. Ask the participant to put the top back on and return to an upright standing posture [1].
 - 3.5.1. LAB MEDIA: IMG_0015.MOV: 00:00-00:05
- 3.6. Palpate the previously placed magnetic bases through the clothing and attach reflective markers onto the magnetic bases sequentially [1].
 - 3.6.1. LAB MEDIA: IMG_0015.MOV: 00:25-00:46
- 3.7. Instruct the participant to turn away from the examiner and flex the neck forward [1].
 - 3.7.1. LAB MEDIA: IMG_0015.MOV: 00:53-01:00
- 3.8. Then, locate the seventh cervical vertebra and place a reflective marker over this landmark [1].
 - 3.8.1. LAB MEDIA: IMG_0015.MOV: 01:05-01:12
- 3.9. Ask the participant to return to a neutral head position and turn to face the examiner [1]. Identify the sternum and attach a reflective marker over it [2].
 - 3.9.1. LAB MEDIA: IMG_0015.MOV. Timestamps: 01:12-01:16
 - 3.9.2. LAB MEDIA: IMG_0015.MOV. Timestamps: 01:16-01:23
- 3.10. Then, palpate the left and right acromion processes and position a reflective marker over the identified landmark [1].
 - 3.10.1. LAB MEDIA: IMG_0015.MOV. Timestamps: 01:35 – 01:49
- 3.11. Instruct the participant to sit comfortably and place the right palm over the left knee [1]. Locate the medial and lateral epicondyles of the right humerus and place a

reflective marker over them [2]. Then, repeat the procedure for the left elbow [3].

3.11.1. LAB MEDIA: IMG_0015.MOV: 01:50 – 02:07

3.11.2. LAB MEDIA: IMG_0015.MOV: 02:07-02:18

3.11.3. LAB MEDIA: IMG_0015.MOV: 02:22-02:30

3.12. Next, ask the participant to place both hands comfortably on the thighs [1]. Identify the radial and ulnar styloid processes and place a reflective marker over this landmark. Similarly, repeat the procedure for the opposite wrist [2].

3.12.1. LAB MEDIA: IMG_0015.MOV: 02:30 – 02:35

3.12.2. LAB MEDIA: IMG_0015.MOV: 02:35-02:44

3.13. Then, palpate the capitate bone in one hand, attach a reflective marker over it, and repeat on the opposite hand [1].

3.13.1. LAB MEDIA: IMG_0015.MOV: 03:05 – 03:10

3.14. Position one reflective marker on the thumbnail and one reflective marker on the ring finger of each hand [1].

3.14.1. LAB MEDIA: IMG_0016.MOV. Timestamps: 00:00 – 00:21

3.15. With the participant seated comfortably, palpate the medial and lateral femoral condyles of the right knee and secure a reflective marker over this landmark [1]. Repeat the procedure for the left knee [2].

3.15.1. LAB MEDIA: IMG_0016.MOV: 00:29-00:49

3.15.2. LAB MEDIA: IMG_0016.MOV: 01:04-01:12

3.16. Then, locate the medial and lateral malleoli of the right ankle and position a reflective marker [1].

3.16.1. LAB MEDIA: IMG_0016.MOV. 01:18-01:23

3.17. Next, identify the first, second, and fifth metatarsal heads of the right foot and place a reflective marker over each landmark [1].

3.17.1. LAB MEDIA: IMG_0016.MOV:01:34-01:54

3.18. Then, palpate the calcaneal tuberosity of the right foot, secure a reflective marker over this landmark [1], and repeat the marker placement for the left foot [2].

3.18.1. LAB MEDIA: IMG_0016.MOV. 01:58-02:04

3.18.2. LAB MEDIA: IMG_0016.MOV. 02:31-02:37

3.19. Attach marker clusters to the forearm, hand, upper arm, thigh, and shank segments bilaterally [1]. Secure each cluster firmly using straps or tape [2].

3.19.1. LAB MEDIA: IMG_0017.MOV: 00:12-00:16, 00:43-00:50, 01:25-01:30, 04:30-

04:35, 04:56-05:00

3.19.2. LAB MEDIA: IMG_0017.MOV: 05:11-05:17

3.20. Then, position reflective markers bilaterally on the frontal bone just above the eyebrows [1], followed by placement on the temporal bones [2].

3.20.1. LAB MEDIA: IMG_0018.MOV: 02:29-02:32

3.20.2. LAB MEDIA: IMG_0018.MOV: 02:32-02:42

3.21. Using a washable skin marker, outline all markers and clusters placed on the skin for consistent repositioning if necessary [1].

3.21.1. LAB MEDIA: IMG_0018.MOV: 01:03-01:25

3.22. Check for loose markers, cluster movement, and occlusion during standing posture [1]. Correct any placement errors as needed and secure any insecure attachments [2]. If no issues are identified, proceed to the object pick-up task [3].

3.22.1. LAB MEDIA: IMG_0018.MOV: 03:25 – 03:33

3.22.2. LAB MEDIA: IMG_0018.MOV: 04:27-04:35

3.22.3. LAB MEDIA: IMG_0018.MOV: 05:06-05:09

4. Motion Capture System Setup and Data Acquisition

4.1. Arrange the motion capture cameras around the capture volume to ensure full-body visibility during forward bending, object interaction, and return to standing [1].

4.1.1. SCREEN: Motion Capture System Setup.MP4: 00:00-00:06

4.2. Define a capture volume large enough to accommodate the full pick-up movement without occlusion [1].

4.2.1. SCREEN: Motion Capture System Setup.MP4: 00:07-00:09

4.3. Calibrate the motion capture system according to the manufacturer's guidelines to establish the global coordinate system [1]. Verify that all cameras detect reflective markers clearly and ensure that no unintended reflective objects are present in the capture area [2].

4.3.1. SCREEN: Motion Capture System Setup.MP4: 00:10-00:30

4.3.2. SCREEN: Motion Capture System Setup.MP4: 00:31-00:34

4.4. Start motion capture recording before instructing the participant to initiate movement [1]. Stop recording only after the participant has completed the task [2].

4.4.1. SCREEN: Data Acquisition. MP4: 00:05-00:17

4.4.2. SCREEN: Data Acquisition. MP4: 00:18-00:25

4.5. Review the recording to ensure all markers are present before proceeding to the next

recording [1].

4.5.1. SCREEN: Data Acquisition. MP4: 00:26-00:28

5. Static Calibration and Object Pick-Up Task for Motion Capture Analysis

5.1. Ensure the participant stands upright within the capture volume [1]. Instruct the participant to abduct both arms to approximately 45 degrees from the body, with the elbows fully extended and palms facing forward [2].

5.1.1. LAB MEDIA: IMG_0021.MOV: 00:00 – 00:08.

5.1.2. LAB MEDIA: IMG_0021.MOV: 00:23-00:25

5.2. Ask the participant to remain still for 2 seconds while counting aloud “one thousand, two thousand” [1].

5.2.1. LAB MEDIA: IMG_0021.MOV: 00:25-00:29

5.3. Instruct the participant to further abduct both arms to approximately 90 degrees from the body, elbows extended, and palms facing downward [1].

5.3.1. LAB MEDIA: IMG_0021.MOV: 00:29-00:31

5.4. Ask the participant to stay still for 2 seconds and count aloud, “one thousand, two thousand [1].

5.4.1. LAB MEDIA: IMG_0021.MOV: 00:31-00:34

5.5. Instruct the participant to lower both arms to the sides and stand in a relaxed neutral posture [1]. Place a standardized object on the floor at a predefined location within the capture volume [2]. Ask the participant to stand upright in a comfortable, self-selected stance facing the object [3].

5.5.1. LAB MEDIA: IMG_0021.MOV: 00:34-00:37

5.5.2. LAB MEDIA: IMG_0022.MOV: 00:05-00:12

5.5.3. LAB MEDIA: IMG_0022.MOV: 00:12-00:19

5.6. Direct the participant to pick up the object from the floor at a comfortable pace, return to a standing position, and hand it over [1].

5.6.1. LAB MEDIA: IMG_0022.MOV: 00:19-00:34

5.7. Maintain a comfortable seated or kneeling position on the floor while retrieving and repositioning the object between trials to ensure consistent placement [1].

5.7.1. LAB MEDIA: IMG_0022.MOV: 00:34-00:49

5.8. Instruct the participant to perform three trials using one hand [1]. Then repeat the task for three trials using the other hand, followed by data cleaning and classification of pick-up strategies [2].

5.8.1. LAB MEDIA: IMG_0022.MOV: 01:00-01:05.

5.8.2. LAB MEDIA: IMG_0022.MOV: 01:30-01:35

Results

6. Results

- 6.1. Participants were divided into three movement strategy groups: squat-dominant, hinge-dominant, and hybrid. There were no significant differences in age, sex distribution, height, or weight among the groups [1].
 - 6.1.1. LAB MEDIA: Table 2.
- 6.2. Knee flexion angles differed significantly across groups for both dominant and non-dominant hand conditions [1], with large effect sizes [2].
 - 6.2.1. LAB MEDIA: Table 3. *Video editor: Highlight the rows "Right knee (dom)," "Left knee (dom)," "Right knee (non-dom)," and "Left knee (non-dom)" with the p value column.*
 - 6.2.2. LAB MEDIA: Table 3. *Video editor: Highlight the "Effect Size (η^2)" column for the four knee rows.*
- 6.3. Ankle joint kinematics demonstrated significant group differences across dominant and non-dominant hand conditions [1], with large effect sizes [2].
 - 6.3.1. LAB MEDIA: Table 3. *Video editor: Highlight the rows "Right ankle (dom)," "Left ankle (dom)," "Right ankle (non-dom)," and "Left ankle (non-dom)" with the p value column.*
 - 6.3.2. LAB MEDIA: Table 3. *Video editor: Highlight the "Effect Size (η^2)" column for the four ankle rows.*
- 6.4. Torso flexion differed significantly between groups for both dominant [1] and non-dominant hand conditions [2], with moderate effect sizes [3].
 - 6.4.1. LAB MEDIA: Table 3. *Video editor: Highlight the row "Torso (dom)" with the p value column.*
 - 6.4.2. LAB MEDIA: Table 3. *Video editor: Highlight the row "Torso (non-dom)" with the p value column.*
 - 6.4.3. LAB MEDIA: Table 3. *Video editor: Highlight the "Effect Size (η^2)" values for the two torso rows.*
- 6.5. Hip joint kinematics did not differ significantly between groups for either dominant [1] or non-dominant hand conditions [2].
 - 6.5.1. LAB MEDIA: Table 3. *Video editor: Highlight the rows "Right hip (dom)" and "Left hip (dom)" with the p value column.*
 - 6.5.2. LAB MEDIA: Table 3. *Video editor: Highlight the rows "Right hip (non-dom)" and "Left hip (non-dom)" with the p value column.*

- 6.6. Greater flexion was observed at the left ankle [1] and left knee [2] during non-dominant hand object pick-up compared with dominant hand object pick-up, with large effect sizes [3].
 - 6.6.1. LAB MEDIA: Table 4. *Video editor: Highlight the row “Left ankle” and compare the “Mean (Dom)” and “Mean (Non-dom)” columns.*
 - 6.6.2. LAB MEDIA: Table 4. *Video editor: Highlight the row “Left knee” and compare the “Mean (Dom)” and “Mean (Non-dom)” columns.*
 - 6.6.3. LAB MEDIA: Table 4. *Video editor: Highlight the “Effect Size (dz)” column for the rows “Left ankle” and “Left knee.”*
- 6.7. Significant differences were also observed at the right ankle [1] and left hip [2] between dominant and non-dominant hand conditions, with smaller effect sizes [3].
 - 6.7.1. LAB MEDIA: Table 4. *Video editor: Highlight the row “Right ankle” and compare the “Mean (Dom)” and “Mean (Non-dom)” columns.*
 - 6.7.2. LAB MEDIA: Table 4. *Video editor: Highlight the row “Left hip” and compare the “Mean (Dom)” and “Mean (Non-dom)” columns.*
 - 6.7.3. LAB MEDIA: Table 4. *Video editor: Highlight the “Effect Size (dz)” column for the rows “Right ankle” and “Left hip.”*
- 6.8. No significant differences were observed at the right knee [1], right hip [2], or torso between dominant and non-dominant hand conditions [3].
 - 6.8.1. LAB MEDIA: Table 4. *Video editor: Highlight the row “Right knee” with the p value column.*
 - 6.8.2. LAB MEDIA: Table 4. *Video editor: Highlight the row “Right hip” with the p value column.*
 - 6.8.3. LAB MEDIA: Table 4. *Video editor: Highlight the row “Torso” with the p value column.*

Pronunciation guides:

1. Singlet
Pronunciation link: <https://www.merriam-webster.com/dictionary/singlet>
IPA: /'sɪŋglət/
Phonetic Spelling: sing·gluht
2. Palpate
Pronunciation link: <https://www.merriam-webster.com/dictionary/palpate>
IPA: /'pæl,pert/
Phonetic Spelling: pal·payt
3. Anatomical
Pronunciation link: <https://www.merriam-webster.com/dictionary/anatomical>

IPA: /ˌænəˈtɑːmɪkəl/

Phonetic Spelling: an·uh·taa·muh·kuhl

4. Spinous

Pronunciation link: <https://www.merriam-webster.com/dictionary/spinous>

IPA: /ˈspɪnəs/

Phonetic Spelling: spy·nuhs

5. Iliac

Pronunciation link: <https://www.merriam-webster.com/dictionary/iliac>

IPA: /ˈɪliæk/

Phonetic Spelling: il·ee·ak

6. Superolateral

Pronunciation link: <https://www.merriam-webster.com/dictionary/superolateral>

IPA: /ˌsuːpəroʊˈlætərəl/

Phonetic Spelling: soo·puh·roh·lat·uh·ruhl

7. Xiphoid

Pronunciation link: <https://www.merriam-webster.com/dictionary/xiphoid>

IPA: /ˈzaɪˌfɔɪd/

Phonetic Spelling: zy·foyd

8. Vertebra

Pronunciation link: <https://www.merriam-webster.com/dictionary/vertebra>

IPA: /ˈvɜːtəbrə/

Phonetic Spelling: vur·tuh·bruh

9. Sternum

Pronunciation link: <https://www.merriam-webster.com/dictionary/sternum>

IPA: /ˈstɜːnəm/

Phonetic Spelling: stur·nuhm

10. Acromion

Pronunciation link: <https://www.merriam-webster.com/dictionary/acromion>

IPA: /əˈkroʊmiən/

Phonetic Spelling: uh·kroh·mee·uhn

11. Epicondyles

Pronunciation link: <https://www.merriam-webster.com/dictionary/epicondyle>

IPA: /ˌɛpɪˈkɒːnˌdaɪl/

Phonetic Spelling: ep·uh·kaan·dyl

12. Humerus

Pronunciation link: <https://www.merriam-webster.com/dictionary/humerus>

IPA: /ˈhjuːməɹəs/

Phonetic Spelling: hyoo·muh·ruhs

13. Styloid

Pronunciation link: <https://www.merriam-webster.com/dictionary/styloid>

IPA: /ˈstɑɪlɔɪd/

Phonetic Spelling: sty·loyd

14. Capitate

Pronunciation link: <https://www.merriam-webster.com/dictionary/capitate>

IPA: /ˈkæpəˌteɪt/

Phonetic Spelling: kap·uh·tayt

15. Femoral
Pronunciation link: <https://www.merriam-webster.com/dictionary/femoral>
IPA: /'femərəl/
Phonetic Spelling: fem·uh·ruhl
16. Condyles
Pronunciation link: <https://www.merriam-webster.com/dictionary/condyle>
IPA: /'kɑːndəl/
Phonetic Spelling: kaan·dyl
17. Malleoli
Pronunciation link: <https://www.merriam-webster.com/dictionary/malleolus>
IPA: /mə'liːələs/
Phonetic Spelling: muh·lee·uh·luhs
18. Metatarsal
Pronunciation link: <https://www.merriam-webster.com/dictionary/metatarsal>
IPA: /,metə'tɑːrsəl/
Phonetic Spelling: met·uh·tar·suhl
19. Calcaneal
Pronunciation link: <https://www.merriam-webster.com/dictionary/calcaneal>
IPA: /kæl'keɪniəl/
Phonetic Spelling: kal·kay·nee·uhl
20. Kinematics
Pronunciation link: <https://www.merriam-webster.com/dictionary/kinematics>
IPA: /,kɪnə'mætɪks/
Phonetic Spelling: kin·uh·mat·iks