## A. Teaching notes for the guided questions of Simulation III

Simulation III employs the parameters in Table I.

| Center of Mass | Male Ref. % | Female Ref. % | Sim. % |
|---|---|---|---|
| $cgf/f$ | 43.0 | 43.4 | 43.2 |
| $cgu/u$ | 43.6 | 45.8 | 44.7 |

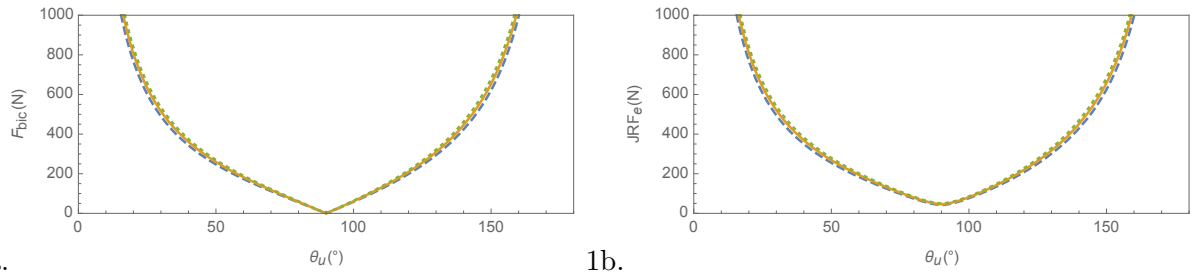
| Body Parameters | Male Ref. % | Female Ref. % | Sim. % |
|---|---|---|---|
| $W_{FA}/W_P$ | 2.5 | 2.1 | 2.3 |
| $W_{UA}/W_P$ | 3.3 | 2.9 | 3.1 |
| $f/H_P$ | 21.5 | 21.8 | 21.6 |
| $u/H_P$ | 17.2 | 17.3 | 17.3 |
| $b/f$ | – | – | 11.0 |
| $d/(f+u)$ | – | – | 25.0 |

TABLE I. Parameters of the human segments in reference and in our Simulation III (the average of male and female).[1,2] The first table is for the positions of center of mass. The bottom table shows the weight and length ratios of body segments as well as the muscle insertions.

- "How do the forces on biceps and elbow joint change with different angles of their elbow bending when $\theta_{arm} = 0°$? Does the change become different for people with different BMI?"

  As shown in Fig. 1, both forces are at a minimum when $\theta_u = 90°$. As $\theta_u$ departs from $90°$, the forces increase symmetrically. The highest forces are experienced at $\theta_u = 0°$, as $180°$ cannot be achieved due to the structure of the arm. Similarly to one of the guided questions in Simulation II, people with larger BMI always experience larger forces, although the difference is less pronounced for the biceps and elbow.

- "What are the optimal and most challenging poses for lifting objects? What is the range of each force experienced for different poses of their arm?" There are two variables $\theta_{arm}$ and $\theta_u$ that determine the pose of the arm.




1a. 1b.

FIG. 1. For an adult with the height of 1.7 m, $F_{bic}$ and $JRF_e$ change with the forearm moving when $\theta_{arm} = 0$ and $W_{bal}$= 30.0 N. The blue dashed, orange solid and green dotted curves are for BMI = 18.5, 25.0, 30.0 respectively.

- "Most forces except $F_{del}$ have the lowest values along the improper rotation axis $\theta_{arm} + \theta_u = 90°$, where the forearm remains vertical while the shoulder extends and flexes. What is the reason behind it?"

In teaching practice, the last two questions can be assigned for assignments for extra credits. The sequence of guided questions is designed to encourage students to adapt their reasoning from one question to the next. Starting with a simple case where the upper arm is horizontal in the first guided question, it is straightforward for the students to geometrically connect that the zero lever arms of the weight of the ball and the weight of the forearm are the reason for the most comfortable position when the forearm is upright and to realize the role of lever arm in equilibrium. Moving to the third question, it leads the students to conclude the same reason that the easiest positions always have the forearm upright. In addition, students can be suggested to learn the tool of contour plots to present quantities with multi-variable dependencies.

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[1] Stanley Plagenhoef, F. Gaynor Evans and Thomas Abdelnour,"Anatomical data for analyzing human motion," Res. Q. Exerc. Sport," **54**, 169–178 (1983).

[2] Howard D. Goldick, *Mechanics, Heat and the Human Body: An Introduction to Physics*, (Pearson, New Jersey, 2001), p. 99.