Stability (please write your answers in the boxes of this sheet)

Name: Student number:

Question 1.

In contact sports, external, mechanical perturbations of an athlete's trunk often occur due to contact with an opponent. This may lead to loss of balance and may limit the athlete's performance in the game, e.g., losing the ball to the opponent. Therefore, it is decided to develop a test to assess the ability of athletes to deal with this type of perturbations. The test consists of the application of a load at the shoulder in the right direction, through the release of a 10 kg mass. The mass is initially held by an electromagnet and then released to exert a force on the cable that is attached to the chest harness worn by the subject. The subject does not know when the perturbation will occur and cannot predict it based on visual or auditory information. The test is performed with the subject initially sitting upright and the pelvis is rigidly fixed to a frame (see Figure 1). Orientation of the trunk in the frontal plane is continuously measured.

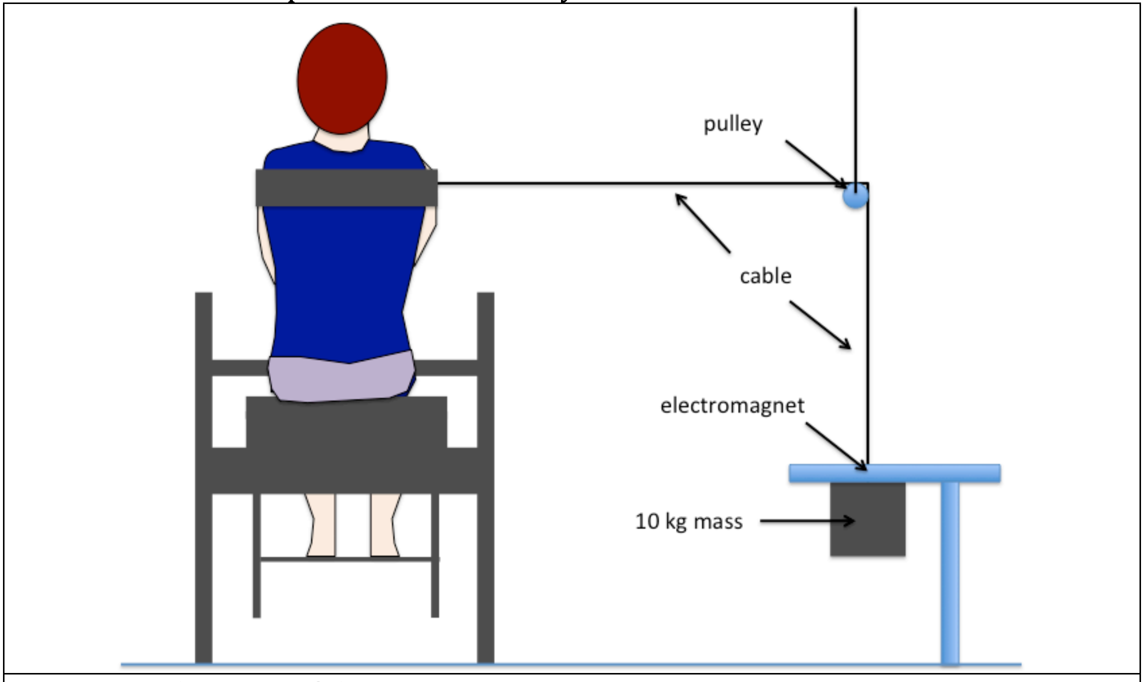

Figure 1. Schematic of the test set-up

Figure 2 represents the data on trunk movement of 3 subjects of roughly equal body mass and height.

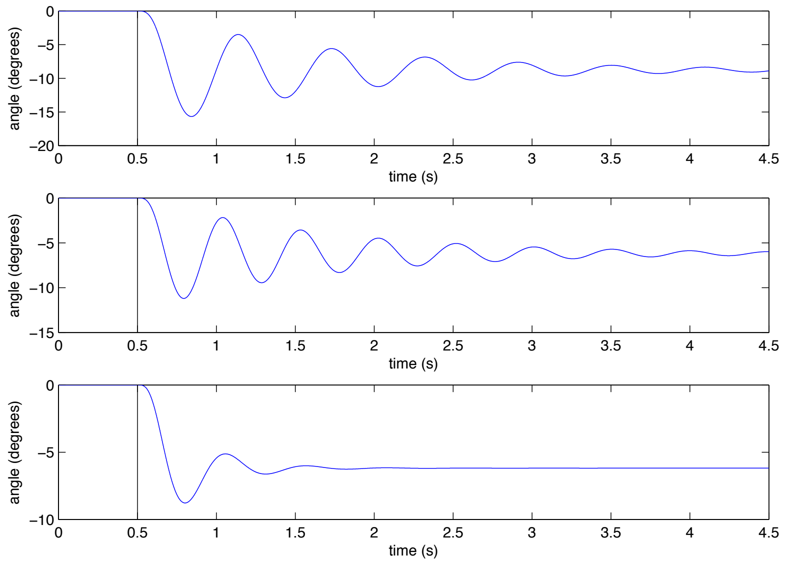

Figure 2. Time series of the trunk angle of three subjects. Zero degrees is upright. The load is dropped at t = 0.5 s.

a) What is the technical term for the type of perturbation applied in this test. (1 point)

Answer 1a

Step perturbation

b) Describe in mechanical terms what the difference is in the control of the subjects displayed in the top two panels and explain which differences between the signals provide this information. (3 points)

Answer 1b

Stiffness is higher in panel 2. This can be inferred from the smaller amplitude and higher frequency of the oscillations and the smaller final displacement.

c) Describe in mechanical terms what the difference is in the control of the subjects displayed in the lower two panels and explain which differences between the signals provide this information. (3 points)

Answer 1c

Damping is higher in the third panel, this can be inferred from the faster decay of the amplitude of the oscillations.

A computer model of this test is created and fitted to the data of the subject in the lower panel of figure 2, such that the output of the model matches that in the figure. The model consists of an inverted pendulum simulating the upper body. Furthermore, to simulate the muscles, the model includes two springs and two dampers that are placed left and right of the midline to stabilize the pendulum in the frontal plane.

d) Increasing the stiffness of the springs in the model can be used to simulate a specific strategy used by subjects tested to control their trunk posture as well as possible. Which strategy is this? Explain why this strategy can be modeled in this way. (3 points)

Answer 1d

Cocontraction of muscles on the left and right side of the trunk can be simulated by increasing spring stiffness in the model. Mechanical stiffness of muscles increases with muscle activation, therefore increased levels of cocontraction will result in increased stiffness.

e) To assess the importance of the anatomy, the moment arms of the springs are doubled and the effect is compared to doubling of the stiffness of the muscles. Which of the two changes of model properties has the largest effect on the kinematic response that the model predicts? Explain why. (3 points)

Answer 1e

Doubling moment arms has a larger effect. The effective stiffness increases linearly with an increase in spring stiffness and quadratically with an increase in moment arm.

The model is modified to represent feedback. The intrinsic stiffness and damping are no longer modeled, instead stiffness and damping occur at some delay to model reflex feedback.

f) Describe qualitatively how the response changes (use the bottom panel in Figure 2 as a reference) when this delay is introduced. (3 points)

Answer 1f

With a delay in the responses the amplitude of the oscillations in figure 2 will grow and the decay of the amplitudes will be less fast (frequency will not change). Overall, performance will thus be lower and with too long a delay the system can become unstable.

g) The delay in the feedback loop implemented in the model is 25 ms. What type of feedback would have a delay of approximately this magnitude? (1 point)

Answer 1g

Muscle spindle or stretch reflexes

During pilot-testing on several subjects it is observed that the performance of the subjects is better when they have their eyes open, even though they cannot predict the perturbation based on visual information as the system that drops the weight onto the cable is placed behind a screen. Apparently, visual feedback does play a role in counteracting this type of perturbation.

h) Describe how one could implement visual feedback in the model. Mention what information would be the input for this feedback loop and what order of magnitude delay you would use. (3 points)

Answer 1h

One could add a second feedback loop with a longer delay (> 100 ms). The input information could be the horizontal position or velocity of the end of the pendulum (representing the head). Obviously these are related but not equal to trunk angle and trunk angular velocity.

i) It is suggested that the testing procedure could be greatly simplified by not perturbing the subjects, but by simply asking them to sit upright and measuring their trunk movements. Based on the kinematics of the trunk, the Lyapunov Exponents of trunk movement could then be calculated. It is expected that the magnitude of the Lyapunov Exponent is correlated to the amplitude of the displacement after a perturbation. Do you share this expectation? Motivate your answer. (6 points)

Answer 1i

The Lyapunov exponent quantifies the rate of divergence of the kinematics of the trunk after a very small change in state that is obtained from the normal unperturbed kinematics. It can thus be expected to reflect the response to very small perturbations. This does not necessarily generalize to larger perturbations (given the non-linearity of the neuromusculoskeletal system). However, several studies have shown relationships between Lyapunov exponents and for example fall risk, which would suggest predictive value for larger perturbations.