

PERTURBATION TASK TECHNICAL REPORT

The Perturbation task has been used in several clinical KINARM studies. This document contains the background and history. Operating instructions and specific details about the protocols used in the studies are included. Task design and implementation information is provided for anyone wishing to recreate or extend the work conducted thus far.

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BACKGROUND

TASK DESCRIPTION

This task measures a participant's ability to use proprioceptive feedback for motor actions. The participant must maintain their index finger at a central target. After a random time period, a mechanical load is applied to the arm and the subject must rapidly counter load and return their finger to the target and remain there for a specified time.

The trial will timeout if they cannot return to the target in a specified time. The applied load is a step function with a sigmoid shape over 10 milliseconds. To avoid hyperextending the joints, the magnitude of the load is constant near the middle of the workspace, but decreases and even reverses direction at extreme joint angles.. This reduction in load is defined using a sigmoid function where zero load is defined as the safety set point.

SCIENTIFIC QUESTION TO BE ANSWERED

With this task we sought to answer the question "Can we quantify the behavioural consequences of altered stretch responses in stroke survivors?"

Stroke is known to alter muscle stretch responses following a perturbation, but little is known about the behavioural consequences of these altered feedback responses. Characterizing impairments in people with stroke in their interactions with the external environment may lead to better long term outcomes. This information can inform therapists about rehabilitation targets and help subjects with stroke avoid injury when moving in the world.

In this study, we developed a postural perturbation task to quantify upper limb function of subjects with subacute stroke (n=38) and non-disabled controls (n=74) to make rapid corrective responses with the arm. Subjects were instructed to maintain their hand at a target before and after a mechanical load was applied to the limb. Visual feedback of the hand was removed for half of the trials at perturbation onset. A number of parameters quantified subject performance, and impairment in performance was defined as outside the 95th percentile performance of control subjects.

Individual subjects with stroke showed increased postural instability (44%), delayed motor responses (79%), delayed returns towards the spatial target (79%), and greater endpoint errors

(74%). Several subjects also showed impairments in the temporal coordination of the elbow and shoulder joints when responding to the perturbation (47%). Interestingly, impairments in task parameters were often found for both arms of individual subjects with stroke (up to 58% for return time). Visual feedback did not improve performance on task parameters except for decreasing endpoint error for all subjects. Significant correlations between task performance and clinical measures were dependent on the arm assessed.

Conclusions: This study used a simple postural perturbation task to highlight that subjects with stroke commonly have difficulties responding to mechanical disturbances that may have important implications for their ability to perform daily activities.¹

¹Bourke TC, et al. Impaired corrective responses to postural perturbations of the arm in individuals with subacute stroke.

TASK OPERATION

TASK INSTRUCTIONS

“In this task, I would like you to put the white dot representing your fingertip inside the red dot. Then you will feel the robot push you away. As soon as you feel the robot push you, come back to the red dot as quickly as you can. Sometimes you will not have the white dot to guide you back to the red dot, but get as close as you can. Try to relax your arm and not anticipate the robot hit.” (Dexterit-E 3.5)

USER CONFIGURABLE PARAMETERS

GENERAL

Task Code: PTBshort

Hand Feedback Behaviour: Controlled by task program

Gaze Feedback Behaviour: Off

Pause/Unpause Behaviour: Repeat trial now

Use random seed: Yes

Data Rate: 1000 Hz

TARGET TABLE

The target table permits specifying different start and end locations in the workspace. Only one central target is used in the standard protocol and the participants must start and end at the same location. All of the parameters in the target table are identical for every trial when using the standard protocol. Earlier variants of the task used multiple target configuration but those variants have been deprecated.

CONSTANTS FOR ALL TRIALS

	X	Y	Visual Radius	Logical Radius	Colour ²
Target 1	0	0	1	1	

X X Position (cm) of the target relative to the local origin

Y Y Position (cm) of the target relative to the local origin

² The colour in Dexterit-E is pure red. It was specified numerically (255000000) rather than picking it with the colour choosing widget.

Visual Radius Radius (cm) used for visual stimulation
 Logical Radius Radius (cm) used for 'Hand-in-Target' logic.
 Colour Target colour in the format RRRGGGBBB or selected from the colour pallet

Target coordinates are relative to the fingertip of the active arm at the joint angles specified below.

Other Parameters:

- Arm: Active
- Shoulder Angle (degrees): 45
- Elbow Angle (degrees): 75
- Frame of Reference: Fingertip
- Invert X values when left arm active: No

The only target used in the standard clinical variant of the task uses local coordinates of (0, 0). The target presented requires the participant’s shoulder to be at 45 degrees and the elbow to be at 75 degrees³. This joint configuration constitutes the start and end target position for this variant of the task.

Joint angles are defined in local coordinates (relative to the shoulder joint) and depend on which arm is chosen as the active arm for the task. When upper arm, forearm, and shoulder plane are all parallel (i.e. arm straight out to the side) the elbow and shoulder joints are at their origin. Joint flexion results in an increase in joint angle while extension results in a decrease regardless of the arm chosen. When the right shoulder/elbow rotates counter clockwise the angle increases. The opposite is true for the left arm.

LOAD TABLE

VARIABLE PARAMETERS

	Elbow Torque	Shoulder Torque	Elbow Safety Set Point	Shoulder Safety Set Point
Load 1	0.5	0	40	0
Load 2	0	1	0	40

Elbow Torque Maximum torque (Nm) magnitude to be applied at the elbow.
 Shoulder Torque Maximum torque (Nm) magnitude to be applied at the shoulder.

³ These angles were chosen so the participants would start at approximately the middle of the range of motion at the shoulder and elbow.

Elbow Safety Set Point Elbow angle where load turns off: defined relative to target angle.⁴

Shoulder Safety Set Point Shoulder angle where load turns off: defined relative to target angle.

Torque is applied based on the local coordinate of the arm chosen for the task. Positive torque will induce flexion and negative torque induces extension. On the right arm a positive torque on either joint will result in counter-clockwise motion at the joint. On the left arm, a positive torque will result in a clock-wise motion at the joint.

CONSTANTS FOR ALL TRIALS

	Ramp	Grade	Offset	Ramp Down
Load 1-2	10	5	80	1000

Ramp Rise time of the perturbation function at perturbation onset.

Grade How quickly load turns off when approaching safety limit.

Offset Location between start target and elbow/shoulder safety set point where load scaling is at 50%. Entered as % of interval [1-100]

Ramp Down Length of time (ms) to ramp loads off at the end of the trial.

Trial Protocol Table

VARIABLE PARAMETERS

	Load	Hand Feedback	Elbow Direction	Shoulder Direction
TP1	1	0	0	Unused ⁵
TP2	1	0	1	Unused
TP3	2	0	Unused	0
TP4	2	0	Unused	1
TP5	1	1	0	Unused
TP6	1	1	1	Unused
TP7	2	1	Unused	0
TP8	2	1	Unused	1

⁴ The elbow/shoulder safety set point is combined with the elbow/shoulder direction in the TP Table to determine the location of the safety limit.

⁵ Load row one creates an elbow perturbation. Torque at the shoulder is set to zero. There is no induced movement so direction is undefined. Any value entered in this column is ignored. Load row two treats the elbow similarly.

Load Row of the load table that characterizes the perturbation
 Hand Feedback Set the status of hand feedback after the perturbation (1=on, 0=off)
 Shoulder Direction 0 = Shoulder flexion, 1 = Shoulder extension
 Elbow Direction 0 = Elbow flexion, 1 = Elbow extension

CONSTANTS FOR ALL TRIALS

	Start Target	1st Target Wait	Wait For Return	Post-Trial Delay	Max Reach Time	Fixed Delay	Random Delay
TP1-8	1	1000	3000	1000	10000	750	500

All times are in milliseconds (ms)

Start Target Row of the Target Table that characterizes the desired starting position for the trial
 1st Target Wait Length of time participant must hold at the start target
 Wait For Return Time to wait between perturbation start and the end of the trial
 Post-Trial Delay Time between trials
 Max Reach Time Maximum amount of time the subject has to reach the target to start the trial
 Fixed Delay Fixed part of delay before perturbation
 Random Delay Random part of the delay before perturbation⁶

BLOCK TABLE

STANDARD PROTOCOL

The following block table was used for the original standard protocol published in Bourke et al. (2015)⁷. It resulted in 72 trials and took approximately 12 minutes per arm.

	TP List	List Reps	Catch TP List	Randomized	Block Reps
Block 1	5-8	1		YES	2
Block 2	1-8	1		YES	8

⁶ The total delay before perturbation in any trial is calculated as Fixed Delay + rand ()*Rand Delay. The rand () function produces a uniform random number on the interval [0, 1]. The result of this is a uniform distribution of delays on the interval [Fixed Delay, Fixed Delay + Rand Delay]

⁷ Ibid. pg. 2

SHORTENED PROTOCOL

The standard protocol was shorted in Jan 2014. The following block table is used on new participants. This results in 32 trials and takes approximately 3 minutes per arm.

	TP List	List Reps	Catch TP List	Randomized	Block Reps
Block 1	5-8	2		YES	1
Block 2	1-4	2		YES	3

EVENTS

The following table lists the event codes defined for the perturbation task. Events such as TRIAL_ABORTED and TIMEOUT may never appear in any of the trials. These indicate an abnormal series of events in a trial. Figure 1 on page 8 outlines the various executions paths and associated events that can occur. The reference to an 'end target' in the definition of TARGET_ON is maintained for historical reasons. The internal structure of the program allows for the desired end position to be different from the starting position. In the standard protocols they are the same.

Event Name	Code	Description
NULL	0	Set when the task is between trials.
STAY_CENTRE	1	Subject must wait at start target.
LEAVE_CENTRE	2	Target light ON, start waiting for subject to leave start target.
TARGET_ON	3	Wait for hand to enter the end target.
PERTURB_START	4	This flag is set when the perturbation block is enabled.
RAMP_DOWN	5	This flag is set when the loads start to ramp down at the end of the trial.
TIMEOUT	100	This flag is set if the subject cannot reach the start target within the specified time.
TRIAL_ABORTED	101	This flag is set when the trial ends unexpectedly. Usually caused by pressing the pause button.

IMPLEMENTATION

TASK FLOW

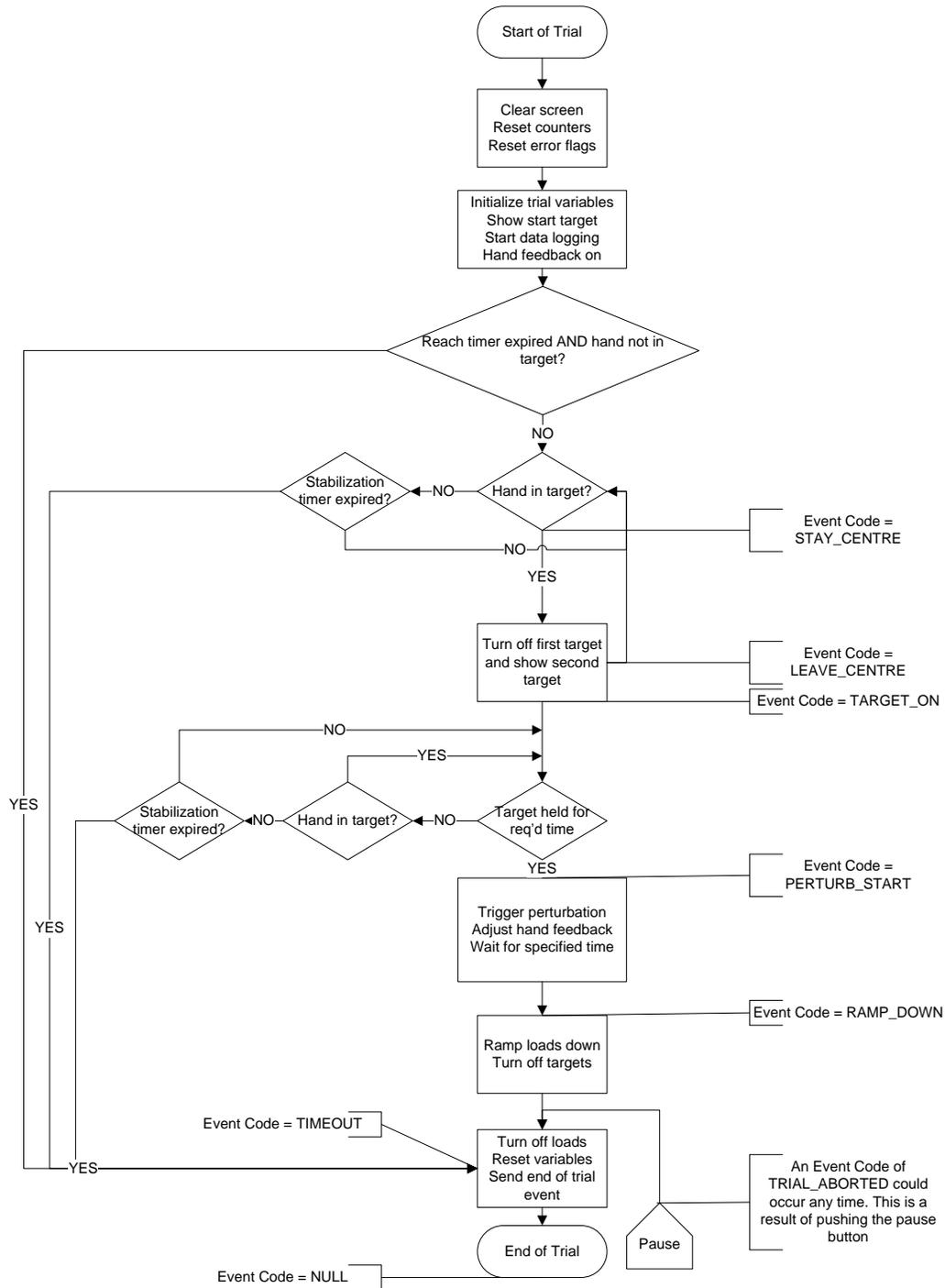


Figure 1: Control logic flow chart

RAMP UP OF LOAD

When the perturbation is triggered, the load is applied as specified in the Load Table parameters Elbow Torque and Shoulder Torque. The initial ramp up follows a sigmoidal function $\alpha = \frac{1}{1+e^{-(t+ramp/2)}}$ where α is the torque scaling command. The duration of the ramp up is set at 10ms to remove high frequency oscillations in the robot, but can be customized by changing the value of the Ramp parameter in the load table.

τ_{EMax} = maximum torque at elbow, from Elbow Torque parameter in the Load Table

$\tau_{EApplied}$ = Torque applied at elbow

$$= \alpha * \tau_{EMax}$$

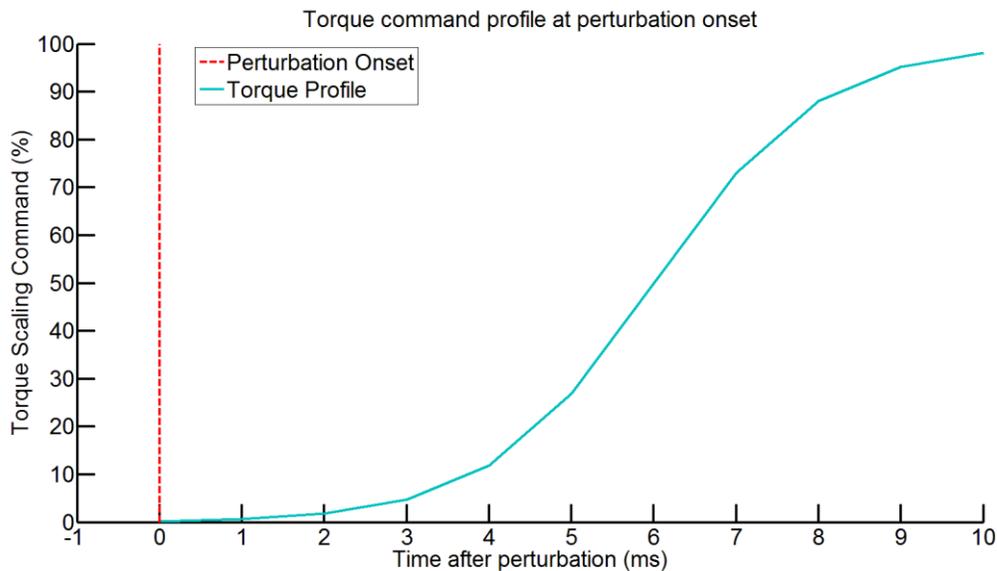


Figure 3: Torque profile at perturbation onset

POSITION DEPENDENT TORQUE SCALING

After the initial ramp period the torque is scaled based on the participants joint angle. The position based scaling is designed to push them away from the target angle. As they approach the safety set point (θ_S), the torque is scaled down smoothly. If the participant overshoots the safety set point they will be pushed back towards it. The torque is scaled as described below. For the purpose of illustration the elbow is used in the following example. The behaviour at the shoulder joint is identical. The task program contains two parallel subsystems that independently control the torques at each joint. Equations account for whether the subject must counter a flexor or extensor load.

$$\theta_i = \text{Joint angle(rad)}$$

$$\theta_T = \text{Target joint angle(rad)}$$

$$\theta_S = \text{Joint angle at safety set point (rad)}$$

The safety set point is defined relative to the start target angle in the target table. The direction of the perturbation, and the Elbow Safety Set Point, is determined by the Elbow Direction column in the Trial Protocol Table.

If Elbow Direction = 0; Δ = Elbow Safety Set Point (flexor torques will be applied)

If Elbow Direction = 1; Δ = -1 * Elbow Safety Set Point (extensor torques will be applied)

$$\theta_S = \theta_T + \Delta$$

θ_{UB} = joint angle above which 100% extensor torque is applied

θ_{LB} = joint angle below which 100% flexor torque is applied

$$\theta_{UB} = \theta_S + |\Delta|, \text{ for extensor load } \theta_{UB} = \theta_T^8$$

$$\theta_{LB} = \theta_S - |\Delta|, \text{ for flexor load } \theta_{LB} = \theta_T$$

R = measure of rotation through the range of θ_T to θ_S

$$= \left(1 - \frac{|\theta_S - \theta_i|}{\Delta} \right) * 100$$

⁸ See Figure 4 on page 14 for examples

$\alpha = \text{torque scaling factor}$

When $\theta_i \geq \theta_{UB}$, $\alpha = -1$

When $\theta_{UB} > \theta_i \cap \theta_i > \theta_S$

$$\alpha = -1 + \frac{1}{1 + e^{-\left(\frac{|R| + \text{midpoint}}{\text{grade}}\right)}}$$

When $\theta_S > \theta_i \cap \theta_i > \theta_{LB}$

$$\alpha = 1 - \frac{1}{1 + e^{-\left(\frac{|R| + \text{midpoint}}{\text{grade}}\right)}}$$

When $\theta_i \leq \theta_{LB}$, $\alpha = 1$

$\tau_{EMax} = \text{maximum torque at elbow, from Elbow Torque parameter in Load Table}$

$\tau_{EApplied} = \text{Torque applied at elbow}$

$$= \alpha * \tau_{EMax}$$

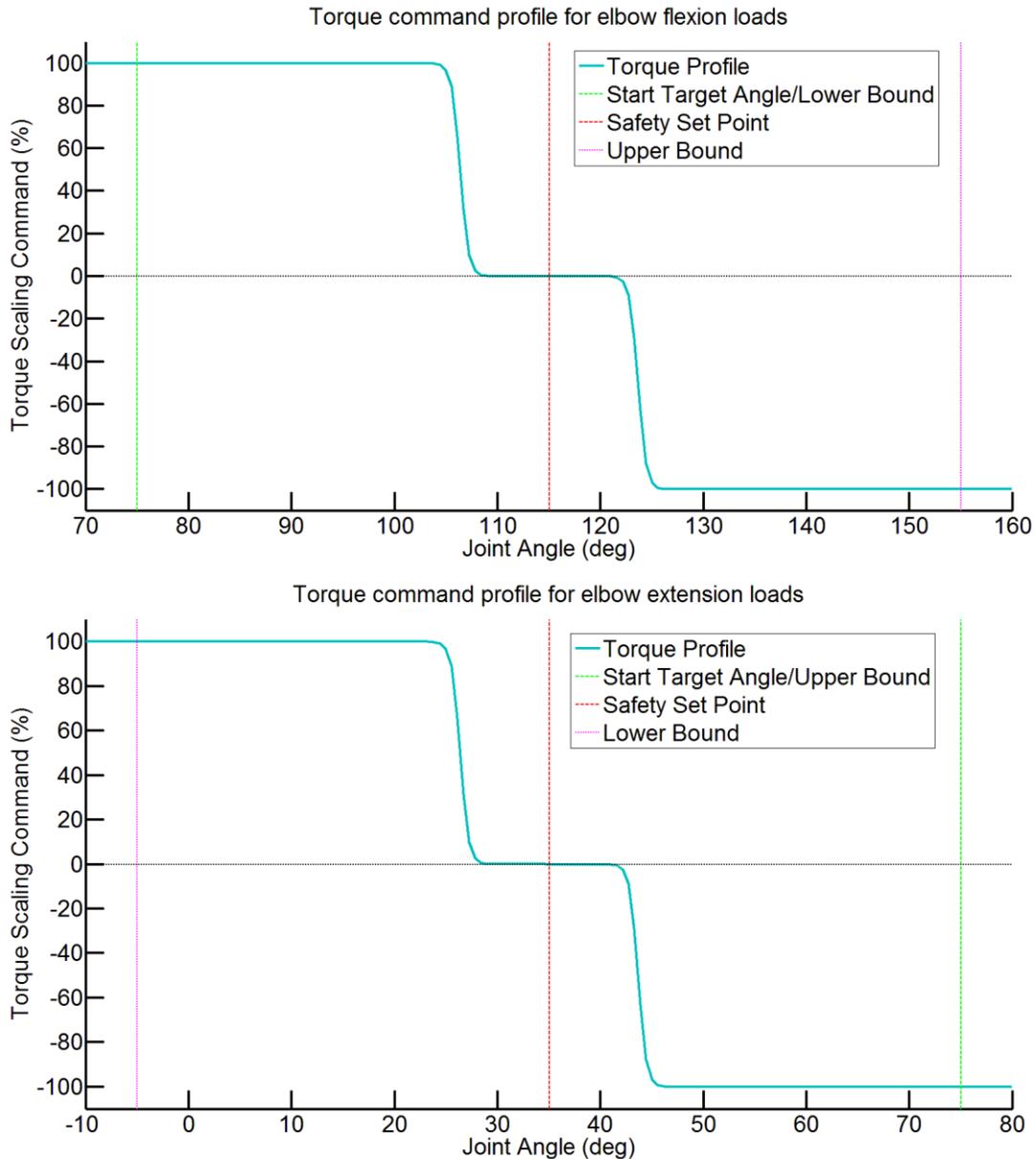


Figure 4: In-trial torque control profile for elbow flexion and extension perturbations

END OF TRIAL TORQUE SCALING

Once the perturbation has been active for the time specified in the TP table parameter *Wait For Return* the torque is scaled from 100% to 0% of current output linearly. The duration of the off ramp is specified in the load table column *Ramp Down*