Adaptation of Task Difficulty in Rehabilitation Exercises Based on the User's Motor Performance and Physiological Responses

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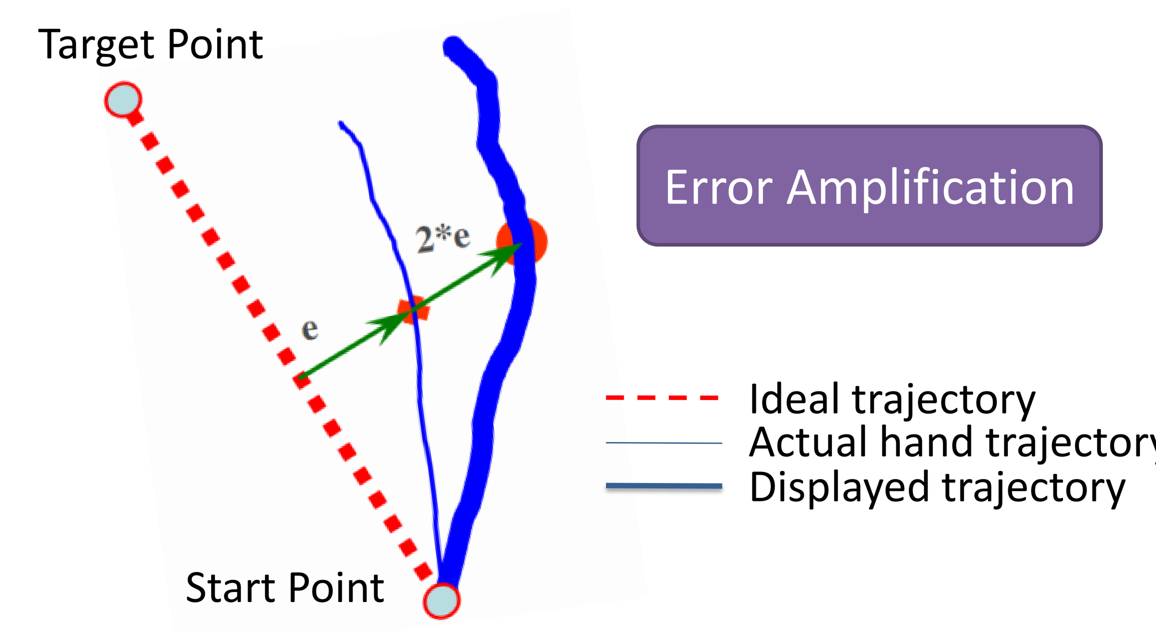
Motivation, Background, and Goal:

- Although robot-assisted rehabilitation regimens are functionally as effective as conventional therapies, they still lack features to increase patients' engagement in the exercise.
- From a motor learning point of view, to avoid boredom or frustration, one needs to be kept at one's desirable difficulty by meaningful manipulation of exercise challenge [1].
- This desirable difficulty can be dependent on both task performance and a person's affective state.
- Performing a reaching exercise with different levels of error amplification (EA) leads to different levels of motor adaptation and affective states. Participants report different levels of perceived difficulty for each error amplification level [2].

- This work is an investigation of the potential to predict a user's desirable difficulty, with the main focus on:



1. Which dataset (motor performance, physiological signals, a hybrid of both) as the prediction variable set returns the highest accuracy;
2. Which of three machine learning approaches – Neural Networks, k-Nearest Neighbor and Discriminant Analysis – predicts participants' desirable difficulty.

Study Protocol and Methods:

- 24 able-bodied participants.
- Five EA levels used as levels of task difficulty: control (no EA), low-gain visual EA, high-gain visual EA, low-gain force feedback & visual EA, high-gain force feedback & visual EA.
- Decay of trajectory error over the training blocks was used to quantify motor performance (figure 3).
- Three physiological signals were used: SCR, breathing rate, and skin temperature.
- Trained machine learning algorithms to predict participants' desired difficulties based on motor performance and physiological signals data.

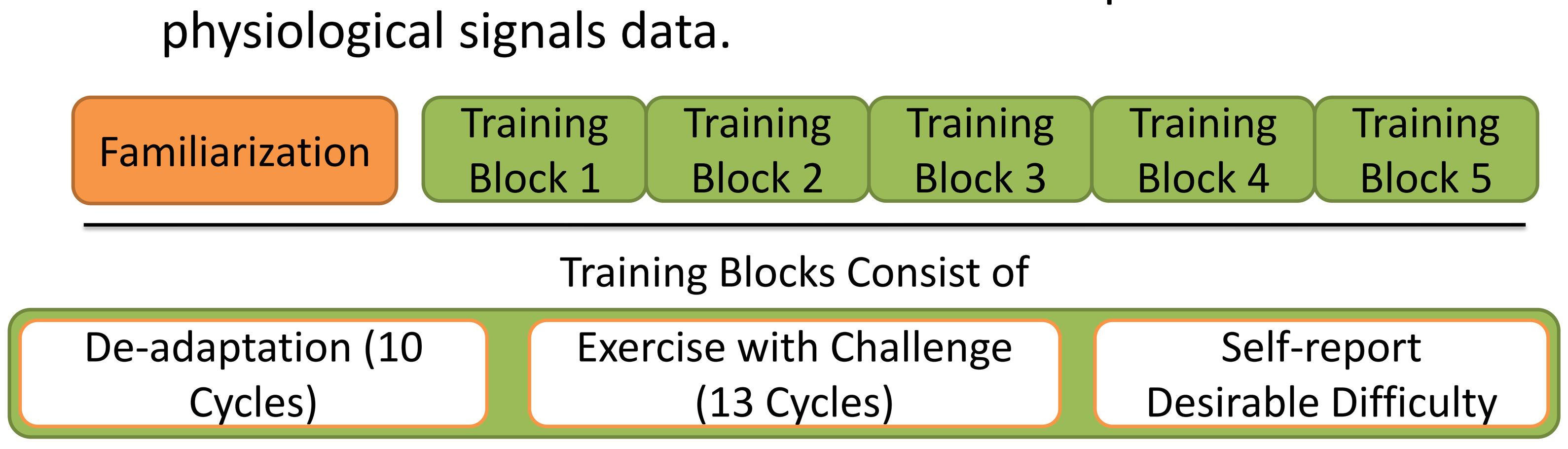


Figure 1. *Study protocol*

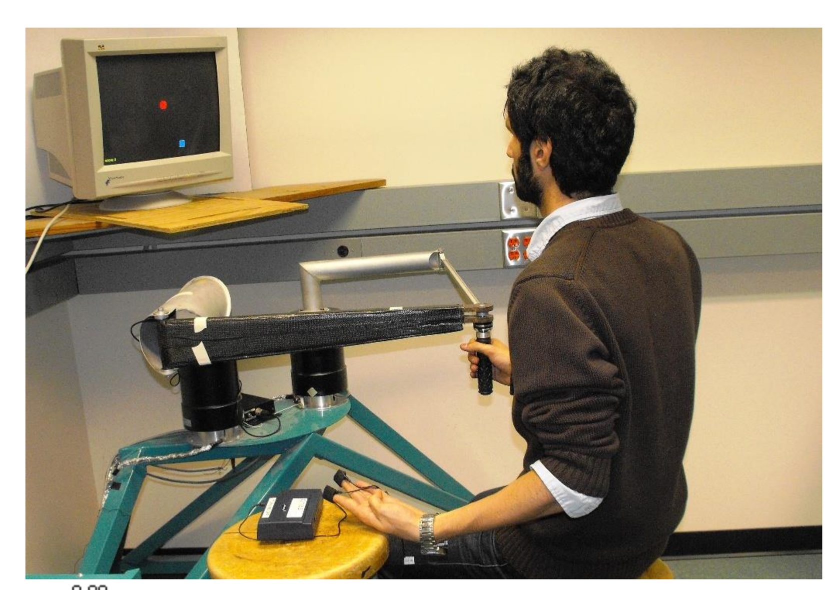


Figure 2. *Hardware used for the study: A participant holds robot's handle while SCR data is being recorded from his left hand's fingertips.*

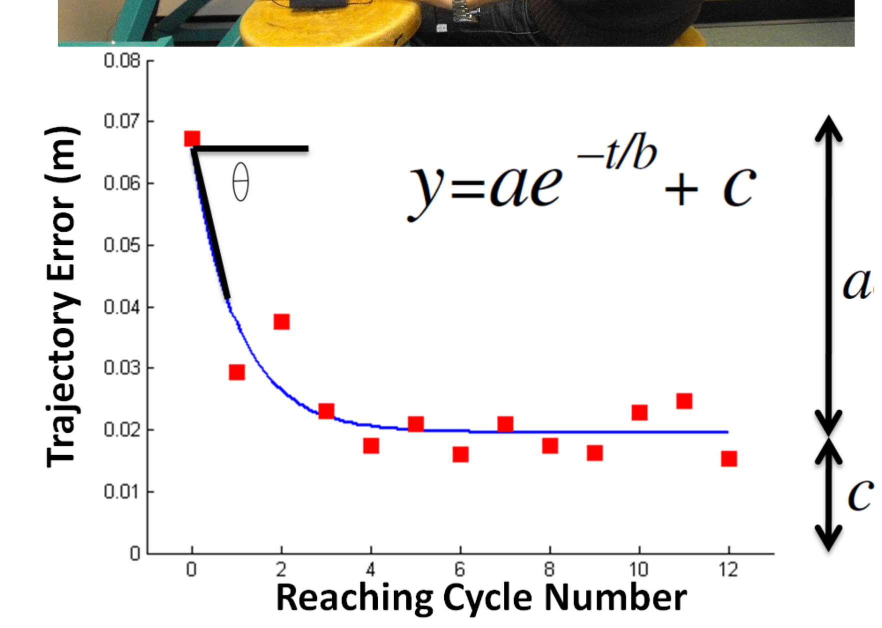


Figure 3. *During practice with challenge, as the participant adapts to the visual distortion, error decays. Variables **a**, **b**, and **c** can be used as motor performance features.*

Results:

TABLE I. ABILITY TO LEARN THE TRAINING SETS

Machine Learning Algorithm	Prediction Variable Set		
	Performance features	*Physiological features*	*Hybrid of all features*
k-Nearest Neighbor	54/80 = 68%	50/80 = 63%	52/80 = 65%
Neural Network	62/80 = 78%	48/80 = 60%	76/80 = 95%
Discriminant Analysis	58/80 = 73%	47/80 = 59%	56/80 = 70%

TABLE II. PREDICTION ACCURACY OF NEW INSTANCES

Machine Learning Algorithm	Prediction Variable Set		
	Performance features	*Physiological features*	*Hybrid of all features*
k-Nearest Neighbor	21/27 = 78%	15/27 = 56%	18/27 = 67%
Neural Network	21/27 = 78%	16/27 = 59%	19/27 = 70%
Discriminant Analysis	20/27 = 74%	16/27 = 59%	18/27 = 67%
Random Number Generator	49%[a]		

[a] Average of 20 trials using all 107 instances

Discussion and Future Work:

- From the most accurate to the least accurate, the three machine learning algorithms were found to be: Neural Network, Discriminant Analysis, and k-Nearest Neighbor.
- Results show that use of motor performance attributes as an input to the prediction models yields the highest accuracy.
- The authors believe that physiological signals can provide supplementary information in predicting desirable difficulty in rehabilitation tasks.
- Future work includes exploring additional ways of combining motor performance and physiological features to achieve higher accuracy rates, the exploration of more sophisticated machine learning methods such as Support Vector Machines (SVM), and studies involving stroke survivors to investigate long-term effects of training with a system capable of providing exercises at the user's desirable difficulty level.

[1] M.A. Guadagnoli, T.D. Lee, "Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning," **Journal of Motor Behavior**, vol. 36, 2004, pp. 212–224.
[2] N. Shirzad, H.F.M. Van der Loos, "Error amplification to promote motor learning and motivation in therapy robotics," in **Proc. IEEE International Conference on Engineering in Medicine and Biology Society** (EMBC), 2012, pp. 3907-3910.