Quantifying the Dimensions of Human Hand Dexterity Through a Survey of Daily Tasks

Ravi Balasubramanian, Brian Dellon, Sujata Pradhan, Spencer Gibbs, and Yoky Matsuoka

Abstract—**The concept of dexterity and its dimensions have been difficult to define through the years, and various research communities have different definitions of dexterity. In this paper, we present a novel approach to understand people's perception of dexterity and its different dimensions in daily tasks. The approach entails a video-based survey where people score different tasks along pre-specified dimensions of dexterity. The results show how the dimensions contribute to an overall dexterity score as well as the importance of each dimension.**

Index Terms—**Dexterity, Hand function, Daily tasks.**

I. INTRODUCTION

Human hand dexterity has been a challenging construct to define due to the inherent structural complexity of the human hand and the variety of tasks it performs. Some of the existing definitions of dexterity include versatile capacity, the ability to carry out harmonious movements, finding an efficient motor solution, and the ability to correctly solve a motor problem in any situation [Latash et al., 1991]. Although these attempts have resulted in conceptual definitions of dexterity, it is still unclear what the key components or dimensions of dexterity are. While previous work has considered task features such as force magnitude, distance traveled, and speed as dimensions of dexterity [Jones, 1998], dexterity includes even more dimensions such as the element of internal models and range of joint motion. Another barrier that has resulted in ambiguity is that dexterity has been defined differently in different domains such as robotics, physiotherapy, hand surgery, and physiology. The overall goal of this project is to identify various dimensions that contribute to dexterity, their relative importance, and a ranking of the dexterity of various daily tasks. We approach this problem by measuring people's perception of the dexterity in various daily tasks through a survey.

II. METHODS

A. Survey structure

The survey, deployed on the internet, consists of a series of questions asking the participant to "score" several daily human hand-based tasks according to pre-defined dimensions related to the overall concept of dexterity.

A pool of twenty common tasks that require fine motor control and are typically associated with manual dexterity was created. Some example tasks were hammering, card shuffling, orange peeling, and keyboarding. Tasks that involved a variety of grasps (palmar, hook, pincer) as well as multiple movement patterns (discrete movements, continuous movements, repeated movements, sequentially linked movements) were included, based on work by Kimmerle et. al., 2003. The tasks were precisely defined using short videos created specifically for this purpose. To help the subject understand the roles played by the hand in the task, we also identified how many fingers were being used. Subjects were asked to provide scores on exactly the task shown in the video and not on how he/she might do the task. The subject was asked to give scores even if they were not familiar with the task.

The ten pre-defined dimensions of dexterity were familiarity with the task, force magnitude, force modulation, stiffness magnitude, stiffness modulation, speed of movements, coordination between joints/timing with an external clock, range of joint motion, the importance of sensory feedback (vision, tactile, proprioceptive), and the amount of practice required.

Each survey was fifteen pages long, received responses on ten tasks, and took about thirty minutes to complete. The survey was structured such that each page required the subject to score, on a scale of 0—5, all the tasks for each dimension. The final page asked for the overall dexterity score for each task. We also collected some demographic information at the beginning of the survey. Three equivalent surveys were created using 10 tasks from the task pool.

B. DATA ANALYSIS

Two statistical techniques were used to analyze the data collected, namely linear regression and principal component analysis. Linear regression was used to find a set of coefficients w_i that can predict dexterity D given the ten dimensions, x_i, i={1,2,..,10}, of the task:

$$D = \sum w_i \cdot x_i \,.$$

Regression analysis will show how each dimension x_i influences dexterity---if the regression coeffecient w_i for dimension x_i is positive, it implies that dexterity increases as the value of that particular dimension increases and vice versa.

Principal component analysis measures the inherit relationship between the dimensions chosen and which combination of dimensions are important.

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III. RESULTS

The number of subjects was 26 (43% female, 77% in the 18—35 age range, 62% from the field of engineering, 11% from the health sciences). The dexterity scores for some tasks were as follows: keyboarding 3.9, playing the violin 4.8, hammering, 1.8, screw driver 2.8, rolling a ball 4.0. Overall, it was noticed that playing the violin was ranked the highest in the overall dexterity score, while hammering was ranked the lowest.

The regression coefficients (and their standard deviation in brackets) for the ten dimensions of dexterity were computed to be {0.01 (0.1), -0.06 (0.1), -0.02 (0.1), -0.11 (0.2), 0.1 (0.2), -0.05 (0.1), 0.39 (0.1), 0.21 (0.1), 0.23 (0.2), 0.30 (0.1)} (r^2 value 0.98). It was noticed that the contribution of the first six dimensions to dexterity were significantly smaller than the last four dimensions. Fig. 1 shows the correlation between the different dimensions, and it was noticed, for example, that force magnitude and practice were negatively correlated.

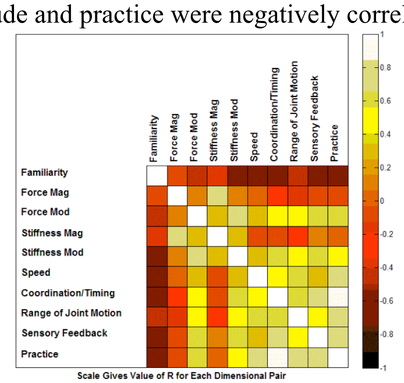

Figure 1: The correlation between the various dimensions of dexterity (white represents high positive correlation, black represents high negative correlation).

Principal component analysis of the data showed that the first principal component explained 55% of the variance in the data, the first two principal components 75%, the first three principal components 85%, and the first four principal components 91%. Fig. 2 shows a biplot of the different dimensions expressed in terms of the first two principal components.

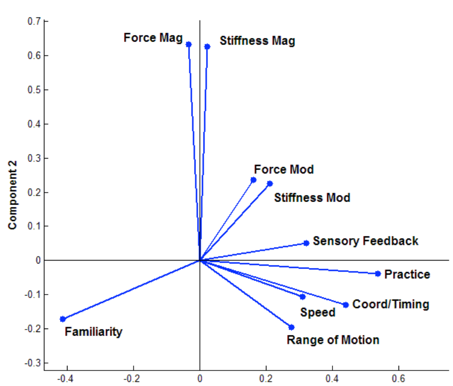

Fig. 2: A biplot of the dimensions of dexterity represented in the first two principal components.

IV. DISCUSSION

A. Relationship between the dimensions of dexterity

The correlation between dimensions (see Fig. 1) was intuitive. It was noticed, for example, that tasks that require more sensory feedback require more practice. Also more practice is required for tasks that require large forces. In contrast, it was noticed that movement speed was negatively correlated with stiffness magnitude.

Principal component analysis provided interesting insights into the key components of dexterity. The first principal component was dominated by dimensions such as practice, coordination/timing, sensory feedback, and speed. All these dimensions represent involuntary aspects of task performance; for example, a person does not have direct control over the sensory feedback inherent to a task. In contrast, the second principal component was dominated by dimensions such as force and stiffness magnitude. These dimensions represent voluntary aspects of task performance.

B. Impact on robotics and rehabilitation research

Dexterity in robotic manipulation is currently defined using robot state spaces and generating control strategies to travel from one state to another (Bicchi, 2000). Our work provides a more intuitive definition of dexterity in terms of daily tasks and using a human-specified metric. Second, it has been difficult to quantify the complexity of daily tasks and design cheap robots or prosthetics that perform tasks of specific complexity levels. This survey makes headway by identifying people's perception of task complexity.

These results will also provide rehabilitation professionals with a framework for progression from objectively quantified simple activities to more dexterous activities for rehabilitation during recovery. It may also be incorporated into current assessment tools of hand function to quantify severity of functional deficits.

C. Limitations

These results are based only on the people's perception of the tasks and the dimensions. It would be better to use quantitative measurements for each dimension to derive a dexterity score. Still our survey sheds light on the importance of different dimensions when combining the dimensions to give an overall dexterity score. A larger task pool and a sample space will also provide strong statistical results.

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