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Should Object Function Matter during Modeling of Functional Reach-to-Grasp Tasks in Robot-Assisted Therapy?

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Abstract— **Recent literature support the idea of using an intense, task-oriented, stroke rehabilitation to promote motor learning and cerebral reorganization. Supporting a task-oriented, robot-assisted therapy approach requires better understanding of the components of real tasks and the limitations and benefits of current trajectory models. We set out to understand natural reach–to-grasp kinematics as it relates to various functional bilateral and unilateral tasks so as to better map this information to a robotic reach-to-grasp therapy systems. To do so, we investigated the influence of arm use and object functionality on four reaching kinematics in reach-to-grasp daily living tasks. We compared our results with the minimum jerk trajectory model used in robot-assisted therapy with the goal of understanding how best to support these real movements in a robotic environment. Eight neurologically intact, right handed subjects participated in the motion analysis study. They completed unilateral and bilateral reaching to objects in the same location with the same orientation, and with handles of the same size and shape. We discuss our results in terms of the minimum jerk model, which is typically used in robot-assisted trajectory planning. Our results showed significant differences in peak velocities, movement time and total displacement across tasks and across arm use conditions.**

I. INTRODUCTION

Individuals who suffer a stroke experience major deficits in motor control that compromise gross and fine motor coordination such as reaching and grasping [1]. Recent literature supports the idea of using intense, task oriented, stroke rehabilitation to promote motor learning and cerebral reorganization [18]. We are currently developing a robotic assistive therapy device that focuses on goal oriented ADL tasks to help address these issues. However its development poses several challenges. Supporting a task – oriented, robot assisted therapy approach requires better understanding of the components of real tasks and the limitations and benefits of current trajectory planning models used to generate movements with the robot. We set out to investigate how object function, the use of the non-dominant hand separately and together with the dominant hand influences the kinematics of the initial reach to the object.

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The literature analyzing reaching to grasp objects of different shapes, sizes and weights is extensive [2-4, 8]. Often dependent variables such as movement time, peak velocity, movement smoothness (jerk) and total displacement are used to quantify the kinematics of the reach. For both stroke and able bodied persons, object distance, orientation, shape and size influence the type of grasp needed and the strategy used to accurately position the wrist to grasp the desired object [2-4,8]. A smooth reach is often characterized by one acceleration and deceleration phase in a point-to-point reaching move.

Although reaching kinematics during bimanual tasks are similar to those in unilateral reaching, they tend to be characterized by lower velocities and longer displacements. These differences are a result of coordinating both hands for grasping. Smoothness is also affected in bimanual arm use. In symmetric bimanual reaching tasks, many observe that movements tend to be smoother and faster when compared to asymmetric tasks [5-7].

In addition to object properties and arm use, the type of task that is performed affects reaching to grasp kinematics. In fact, goal oriented tasks using real world objects were most likely to result in smoother movements, lower movement times and higher peak velocities. There is still a need to examine the kinematics of real activities in the context of robot-assisted therapy.

In planning human movements with the robot, the minimum jerk trajectory model [8] has been used for plotting trajectories of point to point reaching tasks in virtual or real world environments. The model used in robotic therapy often assumes that reaching movements occur with zero initial and final velocities and that suggests that point-to-point reaching movements by humans occur so as to maximize smoothness and minimize changes in accelerations [9-10].

In this paper, we investigate the influence of arm use and functional object use on the reaching kinematics of four self care tasks. We examined unilateral and bilateral reaching to objects that were constrained to the same location and orientation and required the same grasping strategy for both unilateral and bilateral tasks. We compare our results with the minimum jerk model. Our data offers insight into how real-world movements compares with predicted movement data obtained from the minimum jerk trajectory model employed in our robotic therapy system.

II. METHODS

A. Subjects

Data for eight able-bodied, right-hand dominant subjects were used in this study. All of these subjects gave prior consent to participate in this study which was approved by the Institute Review Board of the Medical College of Wisconsin. The mean age for the subjects were 37.6 years. These subjects were instrumented with 12 reflective markers that were attached using hypoallergenic tape to key anatomical landmarks based on a bilateral upper extremity kinematic model (Fig.1) [11].

B. Protocol

The subjects were seated at a table in a resting position with their palms down on the table and their elbows at a 90° during the start and end of each task (Fig.2). A series of tasks (Table 1) were presented in random order. These tasks were completed at a comfortable pace set by the subject. The artifacts used in the non-dominant hand were the fork, spoon, toothbrush and comb, and the artifacts used in the dominant hand were the knife and toothpaste. Each of these artifacts were fitted with custom made rubber foam handles which were the same size and shape and were placed at the same location 7 inches from the edge of the table. The orientation of these objects was kept the same for both unilateral and bilateral tasks.

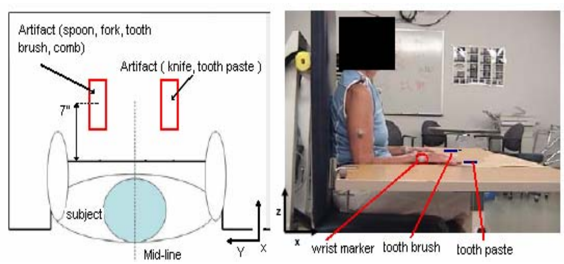

Fig. 1. Set-up for the motion analysis of selfcare tasks. Left: layout of the table with locations of the artifacts (toothbrush, comb, spoon, fork, tooth paste, knife) for the functional tasks described in this paper. The comb, spoon, fork and toothbrush are placed on the non-dominant side. Right : Figure of a subject in the rest position with reflective markers placed on both arms and a toothbrush and tooth paste.

TABLE 1
DESCRIPTION OF ARTIFACTS AND TASKS*.

Tasks	Description	Events	Object Location
Spoon (Uni-ND)	eat pudding with a spoon	Reach, pick spoon, use it, spoon to mouth, return spoon, return to rest.	Spoon : 175mm from table edge
Fork (Bi-ND)	eat cheese with a fork and knife	Reach pick fork and knife, slice cheese with knife, fork to mouth, return for and knife, return to rest.	Fork and knife : 175mm from table edge
Tooth brush (Bi-ND)	Brush teeth	Reach, pick toothbrush and tooth paste, toothbrush to mouth, brush 3 times, return toothbrush and tooth paste and return to rest.	Tooth brush and tooth paste : 175mm from table edge
Comb (Uni-ND)	Comb hair	Reach, pick comb, comb hair, repeat 2 times, return items, return to rest.	Comb : 150mm from table edge

*Tasks analyzed in this paper were a subset of several self care tasks.

C. Data Analysis

Subjects were blinded to the full experiment details and were asked to focus on the task goals. Data were collected using a 15 camera Vicon Motion Analysis System [Vicon Motion

Analysis Systems Inc.; Lake Forest, CA] at 120Hz. The 3-D coordinates in space and an upper extremity model was used to reconstruct the kinematic data for position and orientation of the trunk, shoulder, elbow and wrist [11]. The wrist joint center and angle data were processed using a custom MATLAB program and the resulting data files processed so that the trajectories for both hands align in the same direction. This data was further normalize for position in time and starting positions were made to start at the same point to eliminate the effects such as varying patient arm lengths and distance of object from wrist and arm position at rest. A polynomial 12^{th} order least square fit was used to determine the trajectory data for all three trials for each subject. The average trajectory for each task was obtained by averaging each patient's trials for each task. The data presented in this paper was analyzed for the reach phase where subjects started from the rest position to the point immediately prior to any object manipulation.

Kinematic dependent variables such as total displacement, (TD), movement time (MT), peak velocity (PV), and movement smoothness (MS) were calculated from the non-normalized data. For our data, TD is the sum of the raw instantaneous displacements, PV is the maximum velocity value recorded for the event and MT is the total time required to reach the object. Flash and Hogan's equations were used to derive the minimum jerk model estimate for the average movements for these tasks [9]. The minimum jerk model uses a starting point of zero and an endpoint of the average ending location for each subject to represent the average start and end location of the wrist joint center during reach.

Data analysis was done using Microsoft Excel and MATLAB. From the data obtained, we calculated the mean and standard deviations for each of the kinematic dependent variables. We performed 3 repeated measure ANOVA calculations for our data. The first ANOVA compared subjects against the use of the unilateral and bilateral hands, the second ANOVA compared subjects against the 4 tasks and the third ANOVA was used to compare the unilateral and bilateral tasks with the minimum jerk data. We hypothesized that there would be no differences between arm use conditions, no difference across the functional objects and that the minimum jerk model will accurately predict the natural reaching trajectory.

III. RESULTS

Table 2 summarizes the results of the kinematic dependent variables across the four objects and the two conditions, unilateral non-dominant (Uni-ND) and bilateral non-dominant hand (Bi-ND) for the reaching phase. Figure 2 shows a representative plot of reaching to the fork for all subjects. Figure 3 shows plots for means and standard deviations for the kinematic variables, MT, TD, PV and MS.

A. Bilateral and Unilateral Arm Use

In examining the ANOVA calculations, there were no significant difference between the subjects and the tasks. In the first set of ANOVA calculations there were statistical differences for the PV($p<<0.0001$), MT ($p=0.0009$) and MS ($p=0.019$) properties between Uni – ND and Bi – ND across subjects and differences in MT ($p=0.002$) and PV ($p<<0.014$) were also observed across tasks. We initially assumed that there would be no differences because the objects were similarly constrained. These results suggest that despite this, subjects moved slower during the bilateral condition.

B. Functional Objects Effects

In looking at the second set of ANOVA calculations, there were statistical differences for MT ($p=0.006$) and PV ($p<<0.0001$) between subjects and for MT($p=0.002$) and MS ($p=0.005$) between tasks. The comb task had the highest PV at 478.016 mms^{-1} and the lowest MT of 0.491s. The fork task had the lowest PV of 436.076mms^{-1} with the longest MT of 0.683s. We had the assumption that there would be no differences across tasks because the objects were similarly constrained, however the results suggest otherwise and that subjects had different kinematics for the various objects. It is inconclusive whether the differences seen due to the fork and the comb were wholly due to the object themselves and not just due to the bilateral condition.

C. Comparison of Functional Trajectory and Minimum Jerk Model

For the third set of ANOVA calculations, there were statistical differences in the minimum jerk trajectory's kinematic data across tasks and PV and MT across subjects. Overall, the minimum jerk predicted values that were much lower compared to the tasks performed by the subjects for both the unilateral and bilateral tasks. The velocity for the minimum jerk trajectory went to zero at the end of the reach because it assumes that the trajectory starts and ends at the same location. The locations of the peak velocities for the real tasks were slightly shifted to the right of the minimum jerk predicted midpoint location. The shift appeared to be due to the non-zero end point velocities and the fact that the movement being analyzed is the initial part of a functional task.

TABLE 2
MEAN AND STANDARD DEVIATION FOR REACHING TO GRASP KINEMATIC DATA FOR EACH TASK

	Spoon (Uni- ND)		Comb (Uni - ND)		Fork (Bi-ND)		Toothbrush (Bi-ND)		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	MinJerk
MT (s)	0.6079	0.125	0.491	0.079	0.683	0.198	0.656	0.172	1.000
TD (mm)	163.819	27.379	143.533	29.044	158.354	24.263	162.867	25.873	133.173
PV (mm/s)	472.156	88.689	478.016	90.320	436.076	58.953	437.876	77.111	249.623
MS	2.375	0.722	2.000	0.756	3.167	0.992	2.375	0.628	1.000

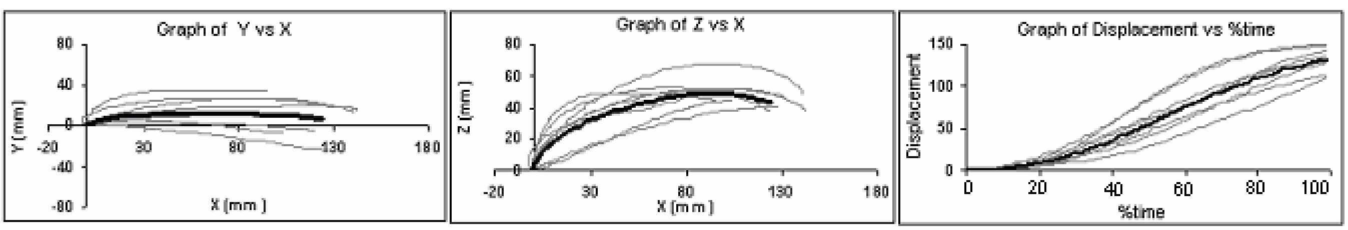

Fig. 2 : Plots showing how average (thick) data was derived from the set of trials performed by each patient (grey) for the fork task. In the first plot Y and X is in reference to the table plane, in the second plot of Z vs. X, the Z axis is aligned with the patient's trunk and the last plot shows the distance vs. % time.

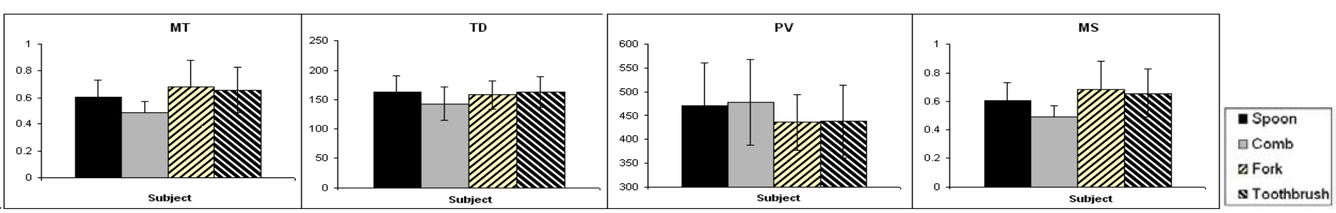

Fig. 3. The following figures show the means and standard deviations for each of the kinematic dependent variables. Top Left : Movement Time. Top Right: Total instantaneous displacement. Bottom Left : Peak velocity. Bottom Right : Movement smoothness.

IV. DISCUSSION

To better understand our results and data obtained, we turn to the literature which suggests that for bimanual reaching toward symmetric objects, synchronization occurs between both hands and that a high intermanual correlation is present [6,12-13]. In addition to this, response selection for a task does have an effect on both unilateral and bilateral reaching kinematics and this is influenced by the object and the task to be performed [7, 14-17]. Subjects had consistent kinematics across tasks and used similar strategies to reach for the various objects. Our overall data from the ANOVA calculations did not produce any significant results for interactions between the subjects. Although the reaching patterns may have been similar across subjects, there were significant kinematic differences between the unilateral and bilateral tasks and also across the 4 tasks. The results suggests that the dominant hand did have an effect during bimanual reaching and that the functionality of each artifact did indeed influence the reaching kinematics which are consistent with studies done by Wu *et. al*. who examined the effects of objects on reaching kinematics [16,19].

In this study, we examined the first reaching portion of the reach to grasp movement. Since the kinematics seen occurred before the object was manipulated and before the task goal was achieved, we hypothesize that the kinematic differences seen were attributed to the subject planning an execution of the entire functional task. The subject, who in addition to executing the current movement, was actively anticipating and planning the next series of moves to complete the next task sub-goal, to reach the next location or to complete the overall goal of the task while considering the object properties. Perceived longer or more complex tasks that require increased interaction or precision have lower PVs and longer MTs and the MS improving for smaller values of MT due to the reach being direct and quick.

The minimum jerk trajectory model is often used in robot therapy systems. When comparing the minimum jerk model with our functional movements, the minimum jerk was found to be significantly different from the actual functional trajectories in that it was much smoother, the tasks were completed with lower total displacements and the velocity was a smooth and uniform bell shaped curve. These differences may be due to the fact that the minimum jerk model does not account for the complete goal of the task, object functionality and unilateral or bilateral hand coordination. An implementation with the robot would not compute the next series of tasks nor account for the object functionality. Instead what is typically done is to propagate from point-to-point.

Most robot assisted therapy systems are primarily based on goal-directed, point-to-point movements that are not always functionally-based. The influence of object functionality implies that a more dynamic controller modeling scheme which could better account for natural human movements and provide improved human machine interaction is important in developing robotic therapy systems[8]. We will use the data gathered in our study and map it on our robotic therapy system to develop a natural reaching to grasp model.

We conclude that there is an influence of object functionality and also the use of the non dominant arm on the reach to grasp kinematics. Our small sample size limits our ability to generalize and more testing is needed.

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