

Scheduling of Hand Movements in Bimanual Tasks

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ABSTRACT

This study investigates the organization of upper body coordination in tasks involving complex visual and manual demands. In the past, bimanual coordination has been approached in the context of symmetric or asymmetric interactions of the two hands. But routine behavior associated with work tasks requires synchronization in time and space of multiple components across multiple concurrent actions. Hence the problem of upper body coordination involves a combination of both symmetric and asymmetric modes of interaction, with a dynamic switching between the two. Although current models may explain the two modes of interaction individually, none of the existing models account for an integration of the two modes from the perspective of task performance. A pilot study was conducted in which subjects performed assembly tasks involving object transfers and manipulations with varying levels of visual and manual demands and performance constraints, such as speed and precision. The preliminary results indicate that among the many different ways in which motor tasks can be performed, the sequencing of movement components is largely influenced by the tendency to maximize synchronization between the 2 hands within the limits of task and resource constraints. Yet, hand movements are almost never concluded simultaneously, and it seems that visual feedback resources limit parallel performance of even purely symmetric motor tasks. There is always a trade-off between the precision demand of the task and the extent of affordable symmetric, parallel performance. High precision or high visual demand of task increases movement duration and also lengthens the final closed-loop phase of movements. This study is the first step in building a model that would be able to simulate any routine one/two-handed object manipulation task.

INTRODUCTION

In many industrial operations, workers perform separate but coordinated tasks with each hand, such as placing a fastener in a hole and then applying a tool to the fastener. Visual demands of the subtasks, and their associated precision requirements may have a strong effect on the way bimanual activities are sequenced. However, current digital human modeling tools have very

limited capability to automatically simulate the sequencing of tasks. The Parameterized Action Representation [1] includes the idea of contingency, that an activity cannot be performed until other activities are completed. But at the level in which coordinated hand tasks associated with a single task are considered, no current model predicts the temporal characteristics of the movement components.

In an attempt to improve the current ability of digital human modeling software to simulate posture and motion from an ergonomic analysis standpoint, and further the understanding of movement coordination, considerable efforts have been made in our laboratory (HUMOSIM) on the development of a general framework that can simulate complex tasks involving multiple movements and object manipulations with only high-level inputs. [15] As part of this effort, a conceptual model is now being developed to describe the planning and coordination of bimanual tasks that would be able to drive digital human figure models with high-level task commands, and thus predict how a person would perform a task in terms of movement pattern and duration. The model (figure 1) will predict the sequencing of movement components and resultant velocity profiles.

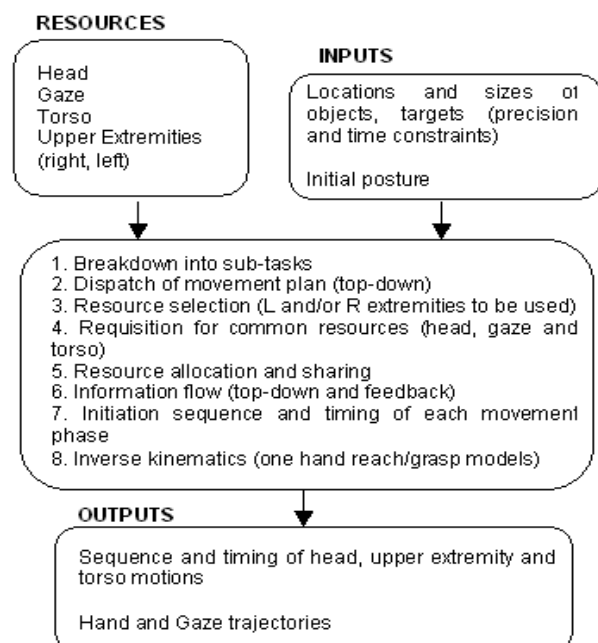


Figure 1. Model input-output specifications

This pilot study investigates the possibility of creating a comprehensive catalog of basic movement components/phases, from which a large range of 'typical' bimanual tasks encountered in an industrial assembly plant could be simulated. The model of bimanual control would simulate any routine one/two-handed object manipulation task by predicting the sequencing of movement phases, nature of their interactions (serial/parallel), and initiation and duration times. Vision, torso and end effectors are modeled as resources used selectively and shared [10], and coordination emerges automatically, while solving the problem of resource allocation, taking into account the information flow at different levels, built-in feedback mechanisms and system constraints.

Previous Work:

Earlier studies of bimanual movements have been restricted to one-phase aiming movements, tasks where both hands are used to acquire a single object or simple reach-to-grasp movements in which both hands are used to acquire a pair of objects. A recent study by Mason [14] examined multi-phasic bimanual movements for the first time, in reach-grasp-place tasks vs. reach-grasp-toss tasks to determine the effect of task context and assimilation effects on coordination.

These studies have found that even when participants were not explicitly asked to synchronize their hands, they exhibited a tendency to do so. Times of movement onset and movement durations were found to be similar for the right and left hands in simple aiming movements [8]. Jeannerod [6] found that movement onset, duration, time to peak velocity and peak grip aperture were synchronized when both hands were reaching to grasp a single object. Kelso et al. [9] found that even when hands were reaching to two targets with different difficulties, although the hands moved at different speeds, the movements were still synchronized. However, Marteniuk et al. [13] re-evaluated the same data and used their own results to suggest that hands are significantly less synchronized than previously reported.

A more recent study by Jackson et al. [5] found that in more complex "reach-to-grasp" movements, movement durations and onset times were synchronized irrespective of whether targets required the same or different levels of difficulty, thus supporting Kelso's findings. Balakrishnan et al. [2] suggested that increasing task difficulty divided attention, and lack of visual integration forced the participants to adopt a more sequential style of interaction. Mason's recent investigation [14] also found movements of the two hands to be synchronized.

Hence, although bimanual tasks have been studied extensively, there is no conclusion as yet on when or why symmetric or asymmetric roles are assigned to the two hands. From a modeling perspective, although each

group has conceptualized a model that could explain a specific aspect of bimanual coordination pertaining to their task context / experimental condition, no consensus on any one model explains the phenomenon as a whole. This is largely due to the fact that despite extensive evidence of symmetry in certain contexts, the potential factors that could drive such symmetric bimanual performance have not yet been quantified. As a result, existing models either predict exclusive symmetric interaction or asymmetric interaction of the two hands.

PILOT STUDY

In this pilot study, subjects performed object 'reach-grasp-place' manipulation tasks with varying visual demands and performance constraints. It was observed that routine tasks (without artificial constraints) involve both symmetric and asymmetric modes of interaction of the two hands, with a dynamic switching between the two. An attempt is made to explain this behavior using a model that integrates both modes of interactions.

METHODS

Subjects:

Two right-handed subjects, a 25 year old male and a 29 year old female, participated in this experiment as volunteers. The experiment was approved by the Institutional Review Board of the University of Michigan. Both subjects had normal vision and were free from any neurological or musculo-skeletal disorders.

Experimental Setup:

Three tables were placed around the subject: One to the right, one to the left and the third in front, perpendicular to the sagittal plane, as illustrated in figure 2.

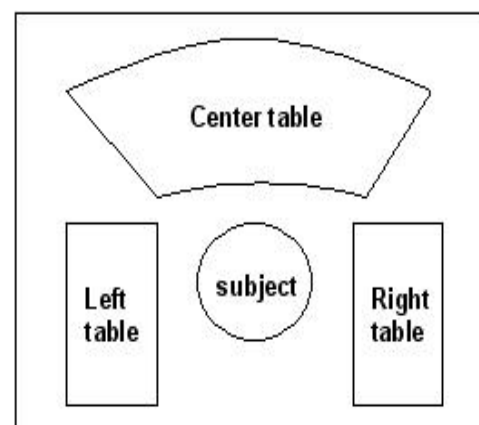


Figure 2. Experimental Setup

An eight-camera Qualisys® motion capture system was used to record kinematic data sampled at 60 Hz. Reflective markers were placed on selected body landmarks to record the subject's hands, arms, torso and head movements as illustrated in figure 3.

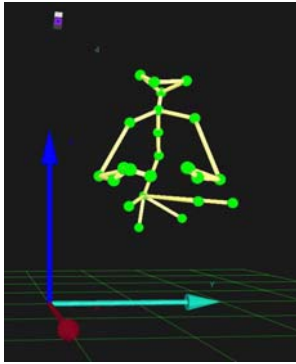


Figure 3: Marker Setup of a subject

Eye movements were recorded simultaneously using a head mounted eye tracking system (ASL eye trac 6.0®). The direction and point of gaze were also monitored on line on a video screen (figure 4).

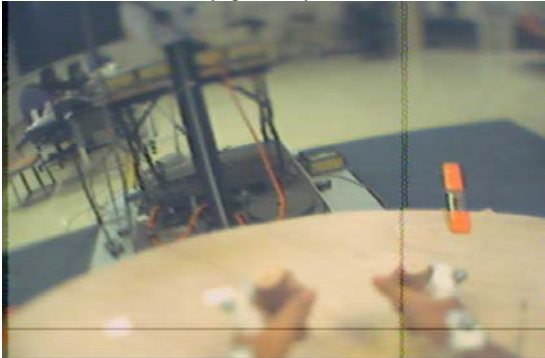


Figure 4: Example of a scene from the video camera mounted on the eye tracker, superimposed with gaze location indicated by the cross hairs

Procedure:

Subjects were seated and asked to perform object manipulations that involved moving the hands from an initial position (on their laps) to grasp a pair of cylindrical objects using a pinch type grip, lifting them from their original locations, moving them to their respective target locations, and returning their hands to the initial positions. The left hand always picked the object on the left and moved it to the left target location, and vice versa for the right, i.e., the task did not require any crossing over of the two hands. Although they were not explicitly instructed to manipulate the objects simultaneously, the tasks were symmetric in principle, and a symmetric performance was expected. Several placement precision demands were required to affect the visual demand and divide visual attention. This procedure allowed us to investigate how effectively visual information is integrated.

Movement speed was not specifically constrained: subjects could move at a self-determined pace. Nevertheless, in order to discourage subjects from taking infinitely long times to complete the tasks, an attempt was made to recreate an industrial setting, where faster performance does have a reward. So they were encouraged to perform the tasks as naturally fast as possible. The only constraint was on accuracy, with zero error tolerance.

Two pairs of light weight cylinders, of diameters 30 mm (Ob 1) and 60 mm (Ob 2), and 120 mm height, were used as objects to be manipulated. Target locations consisted of circles drawn on the surface of the table. The diameter of these target-circles was varied and so did their location, in an absolute sense and with respect to one another. The initial positions of these cylinders were predetermined locations on one or more of the three tables, while all the targets were always located on the center table (figure 5).

For each pair of objects: The pickup locations of the objects for the manipulation task were one of the following four conditions:

1. 50 mm apart, RR (both on the right table)
2. 50 mm apart, LL (both on the left table)
3. RL (one on the right table, one on the left table)
4. 50 mm apart, CC (both on the center table)

The final target locations were always on the center table and constituted the following four conditions:

- I. Diameter of target circle = object diameter (30 mm for Ob 1, 60 mm for Ob 2)
 - a. Distance between target locations=30 mm (C1)
 - b. Distance between target locations=200mm (C2)
- II. Diameter of target circle = 2 X object diameter (60 mm for Ob 1, 120 mm for Ob 2)
 - a. Distance between target locations=30 mm (C3)
 - b. Distance between target locations=200mm (C4)

Thus for each pair of objects, there were a total of 16 test conditions: (RR, LL, RL, CC) X (C1, C2, C3, C4).

All trials were randomized and each trial was repeated eight times. Inter-trial intervals were of approximately 15 seconds. Before each trial, the subject was allowed to see the locations of the objects and the targets. Data was collected after giving the subject enough time to "learn" the task. This was done to ensure that their behavior closely resembled that of an average worker in a plant that was neither exceptionally skilled nor novice to the task. The last three repetitions of each condition, when the behavior had reached a steady state, were used for analysis.

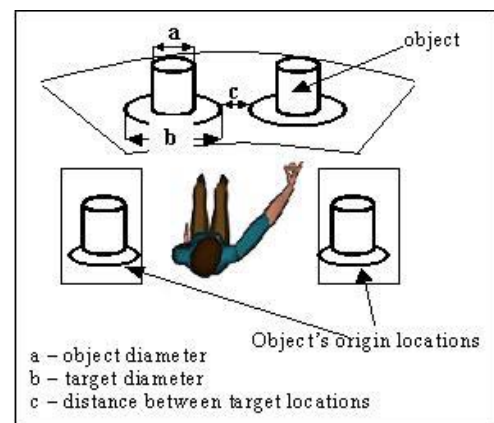


Figure 5: Symmetric task performance: setup