Perceptual-Motor Relations in the Coordination of Catching Behavior

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Abstract

In the case of reaching and grasping for stationary objects, the hand and arm become functionally coupled so that the relative timing of finger closing is preserved across several transport speeds and different initial conditions (Wallace & Weeks, 1988; Wallace, Weeks & Kelso, 1990). We have also found that the size of maximum aperture and velocity of the hand opening and closing is related to the movement time of transport. The present experiment was conducted to determine whether some of these same characteristics could be observed in a simulated catching task where an object to be grasped was moving and the hand was stationary. Six subjects were required to grasp (catch) a vertical dowel transported toward the hand on a small treadmill. The subject's hand rested on the end of the treadmill in an initial "pinched" index finger-thumb position. Thus, catching entailed opening and finally closing the hand to grasp the dowel, then lifting it off the treadmill a few centimeters. A WATSMART motion analysis system monitored both the movement of the object and finger and thumb movement. Six different object velocity conditions were presented. The results indicated that maximum aperture and hand opening (and closing) characteristics were dependent on object velocity. High within-subject correlations were prevalent between the total movement time of aperture and the "tau margin", a perceptual variable (e.g. Lee & Reddish 1981; Bootsma & VanWierigin, 1990). Thus, evidence was provided for a perceptual-motor relation or pattern in this type of task.

Introduction

In reaching and grasping for stationary objects, the hand and ipsilateral arm become coupled in such a way as to preserve the relative timing of finger closing across various transport speeds (Wallace & Weeks, 1988; Wallace, Weeks & Kelso, 1990). This finding suggests that only one pattern of behavior, characterized by relative timing, is preferred in this type of task. In the present study, we asked whether similar relations might be found in the case of catching behavior where the hand is stationary and an object to be caught is moved towards the hand at different velocities. Since there are many tasks which require the synchronization of one's motion with a regularly occurring environmental event (see Kelso, Delcolle & Schoner, 1990), it seemed appropriate to determine whether hand motion could be synchronized to an incoming object, as in the case of catching.

To investigate this question, we observed perceptual-motor relations between an object to be caught and the formation of the hand in anticipation of the object. On every trial, we calculated the *tau margin* at hand opening and at hand closing, defined as the distance between the object and the observer over the relative rate of approach (see Bootsma & van Wieringen, 1990). Lee (Lee, 1976; Lee & Reddish, 1981; Lee et al., 1983) has shown that people and birds gear their actions to the tau margin which can be directly picked up through the optic variable *tau*, defined as the relative rate of dilation of the image on the retina. Lee has argued that tau specifies time-to-contact under constant velocity conditions. However, as pointed out by Bootsma & van Wieringen

(1990), tau does not necessarily specify the type of action employed since tau is only a perceptual variable. We assumed that people would use the information contained in the tau margin to help catch an incoming object. Of particular interest was the manner in which the formation of the hand, characterized by changes in aperture between the index finger and thumb, would vary both within and across different object velocities. Thus, several questions were explored:

1. Within a given constant object velocity condition, would subjects initiate their catching response at a critical tau margin? Would subjects produce a stereotyped catching response (similar overall movement time) or would their responses vary across different object velocity conditions?
2. Is the tau margin at initiation of the catching response the same across different object velocities?
3. Is there a relationship between tau margin at initiation of the catching response and the overall movement time of the catching response, and, what is the strength of this relationship both within and across different object velocities?
4. Can any type of relative timing between the catching response and the trajectory of the object be observed? Will relative timing change as a function of object velocity?

Method

Subjects. Six right-handed volunteers (3 male, 3 female) ranging in age from 20 to 25 years old served as subjects.

Apparatus. The apparatus which supported movement of the object to be caught (a vertically positioned dowel) was a small motor driven treadmill mounted on a table top. The treadmill was situated to allow dowel movement toward the hand in the subject's frontal plane as seen in Figure 1. A seating on which the dowel rested was permanently secured to the treadmill belt so that movement of the belt caused the seating to move toward the subject's hand from a common starting position 40 cm in front of the hand. The dowel, mounted upright in the vertical plane atop the seating, was transported toward the subject's hand such that a catch of the dowel caused it to be separated from the seating. The dowel stood 14 cm in height with a diameter of 1.5 cm. To standardize hand position, a padded wrist support was mounted at the near end of the treadmill upon which the subject positioned the medial aspect of the wrist (see Figure 1) with the hand extended unsupported toward the dowel on every trial.

A potentiometer switch allowed the experimenter to control voltage to the treadmill motor with the result being controlled variations in treadmill velocity, thus velocity of the dowel. Operation of the motor was such that velocity profiles of dowel movement resembled ramp functions. During the experiment, dowel movement, and finger and thumb movement were recorded via a WATSMART motion analysis system at a sampling rate of 100 Hz. Infrared emitting diodes (IREDS) were attached to the top of the dowel, over the lateral portion of the distal phalangeal joint of the index finger, over the medial portion of the distal phalangeal joint of the thumb, and to the dorsal hand at the area intersecting thumb and index finger (over the flexor pollicis brevis). IRED data was collected on-line as subjects performed velocity condition for Tau margin and finger-thumb movement time. As seen in Figure 10, with the exception of Subjects 1 and 2, correlations for each velocity condition were quite high within a subject. Thus, increased object velocity resulted in opening occurring with shorter periods of time before contact, while requiring shorter periods of time for a grasping cycle to occur; the net result was that each of these periods of time covaried closely regardless of velocity condition.

Percent Time to Hand Opening. A relative timing analysis examined the time elapsed from the initiation of dowel movement to the initiation of hand opening as a percentage of total movement time of the dowel. As displayed in Figure 11, there was a significant decrease in the percentage of time elapsed from initiation of dowel movement to initiation of opening with increased dowel velocity, $p<.05$.

Percent Time to Hand Closing. As indicated in Figure 12, a significant decrease occurred in percent time to closing as dowel velocity increased, $p<.05$. A Newman-Keul's post hoc analysis indicated only the most rapid condition to differ significantly from all others ($p<.05$); no other pairs of means differed significantly.

Discussion

1. The tau margin at the initiation of the catching response varied both within and across different object velocities. In general, tau margin reduced as object velocity increased. No evidence was provided for a critical tau margin that was used to

initiate the catching response either within or across object velocities.

2. In 4 of 6 subjects, movement time of the catching response decreased as object velocity increased. This type of scaling between the hand and object velocity, shown here for apparently the first time, is similar to the scaling observed between the hand and arm in reaching and grasping tasks (Wallace & Weeks, 1988; Wallace et al. 1990).

3. Considerable evidence was provided for what has been termed "compensatory variability" (Bootsma & van Wieringen, 1990) in that high correlations between the tau margin and movement time of the catching response were observed.

4. The timing of the aperture closing relative to the transport time of the object remained constant except in the fastest object velocity condition. Whether this represents two relative timing patterns, must await future work which investigates this behavior at higher object velocities.

Finger-thumb Movement Time. As seen in Figure 4, increased dowel velocity resulted in subject's using significantly less time to perform an opening and closing cycle of the finger and thumb ($p<.05$).

Aperture Size at Initiation of Final Closing. Figure 5 indicates that aperture size at final closing increased significantly with increased dowel velocity ($p<.05$). A Newman-Keul's post hoc analysis on means indicated that aperture in the fastest velocity condition was significantly different from aperture in each of the four slowest conditions ($p<.05$), but not the fifth fastest condition. No other pairs of means were found to differ significantly.

Distance Between Dowel and Hand at Opening. As indicated in Figure 6, increased dowel velocity resulted in subjects initiating hand opening when the dowel was further from the hand (significant at $p<.05$).

Distance Between Dowel and Hand at Closing. While Figure 7 indicates a significant increase in distance between dowel and hand at closing at each increase in velocity, a Newman-Keul's post hoc analysis revealed only the most rapid velocity condition to be significantly different from each of the other conditions, $p<.05$. No other pairs of means differed significantly.

Tau Margin at Hand Opening and Closing. As indicated in Figures 8 and 9, Tau margin at hand opening and closing decreased as dowel velocity increased ($p<.05$).

Tau Margin and Finger-thumb Movement Time Relationship. Correlation coefficients were calculated for each subject in each the catches and subsequently digitized, smoothed, and differentiated to render displacement and velocity records for the dowel, finger, and thumb.

Procedure. Subjects were seated with the right wrist placed on the padded wrist support and the right elbow flexed at 90 degrees (see Figure 1). Before dowel movement initiation, the thumb and index finger were held together in a pinch position. Subjects were instructed to watch the dowel throughout its trajectory, grasp it between thumb and index finger, and slightly lift the dowel from the treadmill. No particular instructions or strategies about moving the index finger or thumb to perform the catch were provided to the subjects.

Subjects performed 15 catches (trials) at each of six different dowel velocity conditions (16, 20, 23, 28, 37, and 54 cm/s) with conditions administered in a fixed order from slow to fast. Each trial was initiated by the experimenter after a verbal ready cue and a one second preparation period for the subject to assume the finger-thumb pinch position.

Results

Displacement Tracings. Figures 2 and 3 display typical tracings of dowel displacement, the associated finger-thumb aperture, and the velocity profiles for aperture, and dowel movement. Figure 2 is a trial from the slowest velocity condition while Figure 3 is from the fastest velocity condition for the same subject.

Dowel Kinematics. Dowel movement time and dowel velocity each varied significantly across velocity conditions ($p<.05$). Mean movement times and velocities are presented in Table 1.

References

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Table 1

Mean dowel movement times and velocities (SDs in parentheses)

	Velocity Condition					
	1	2	3	4	5	6
Movement Time (s)	2.2 (.1)	1.8 (.1)	1.5 (.15)	1.3 (.1)	1.0 (.05)	0.7 (.1)
Velocity (cm/s)	16 (1)	20 (1)	23 (1)	28 (2)	37 (2)	54 (4)

FIGURE 1

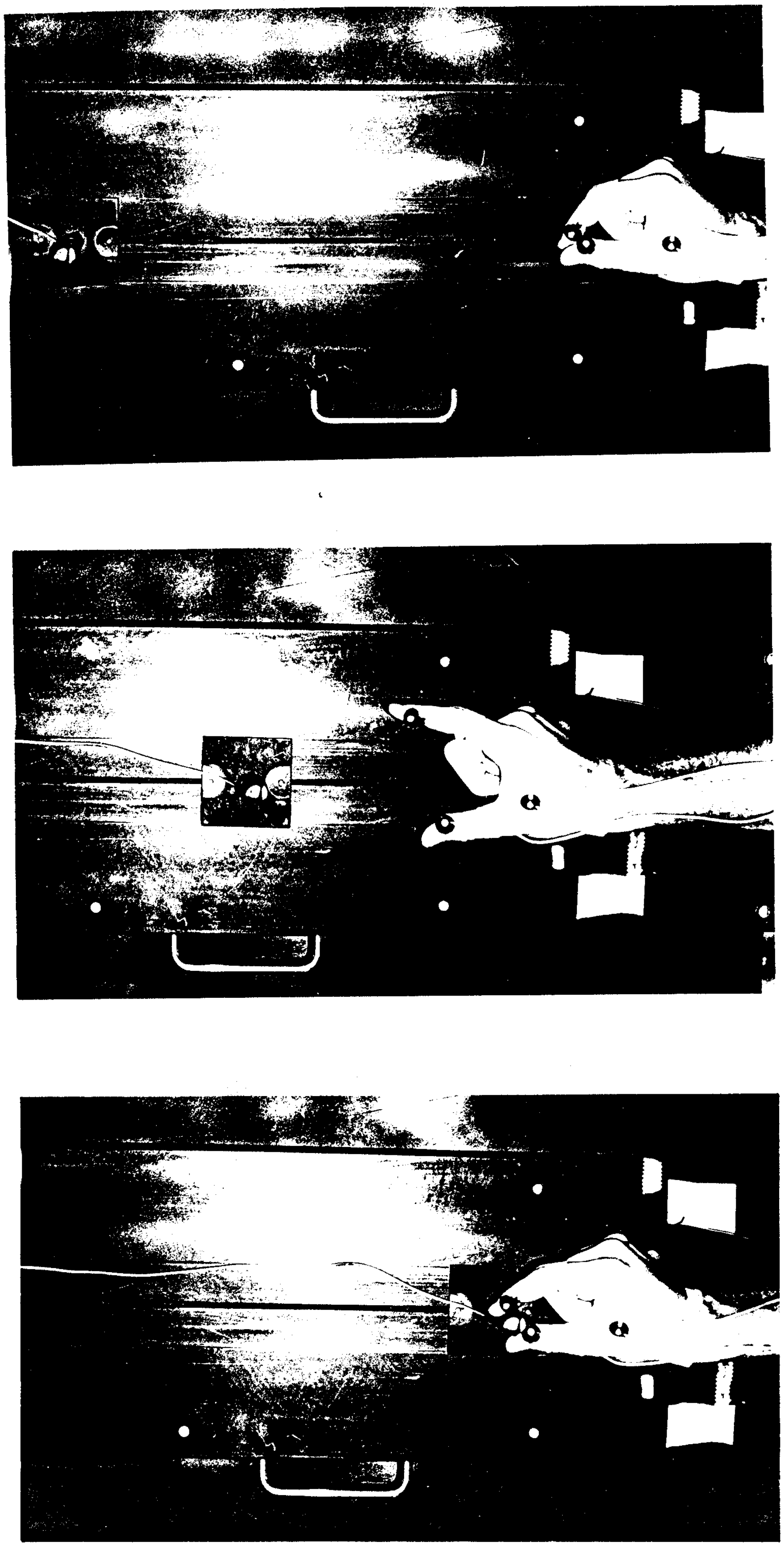


FIGURE 2

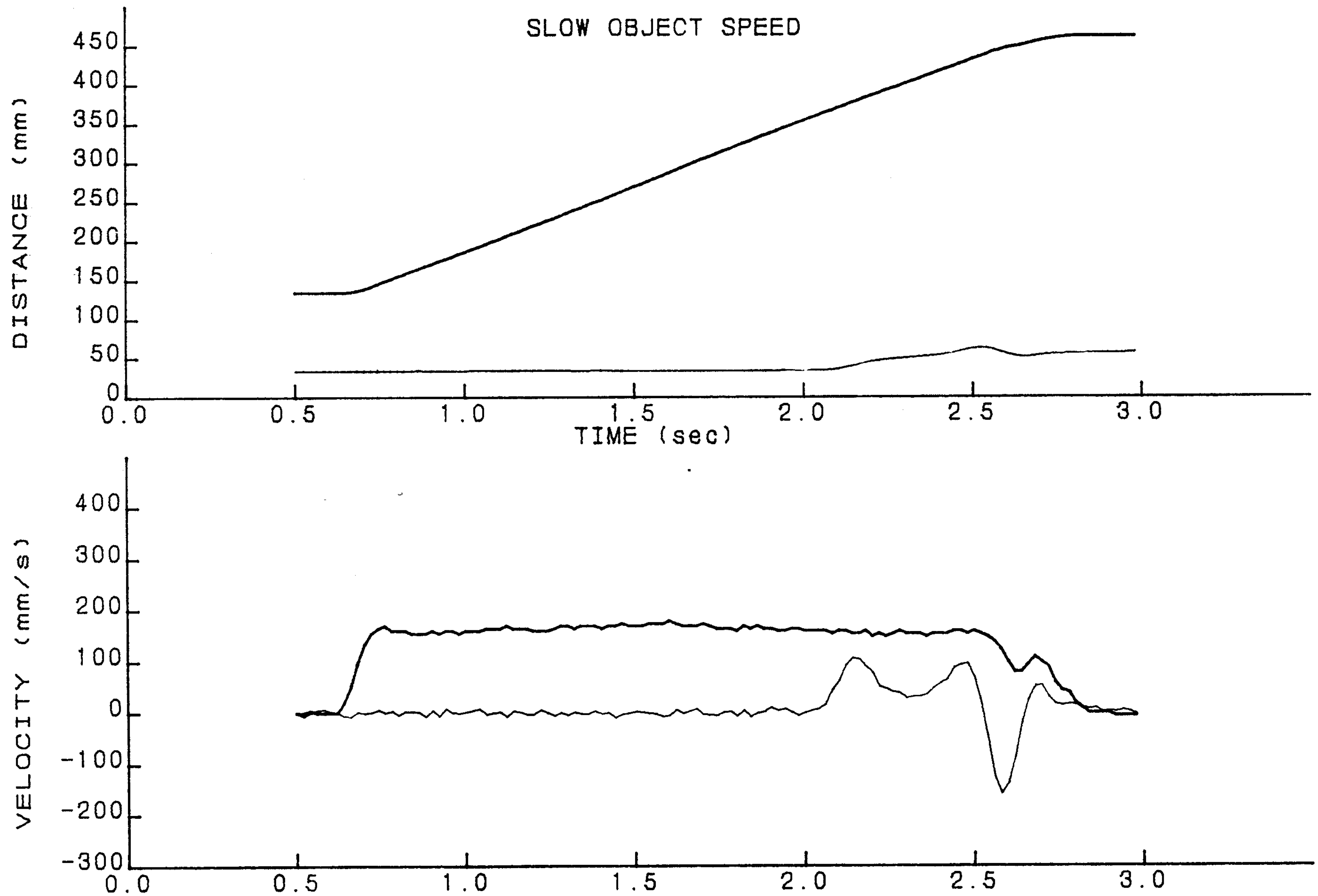
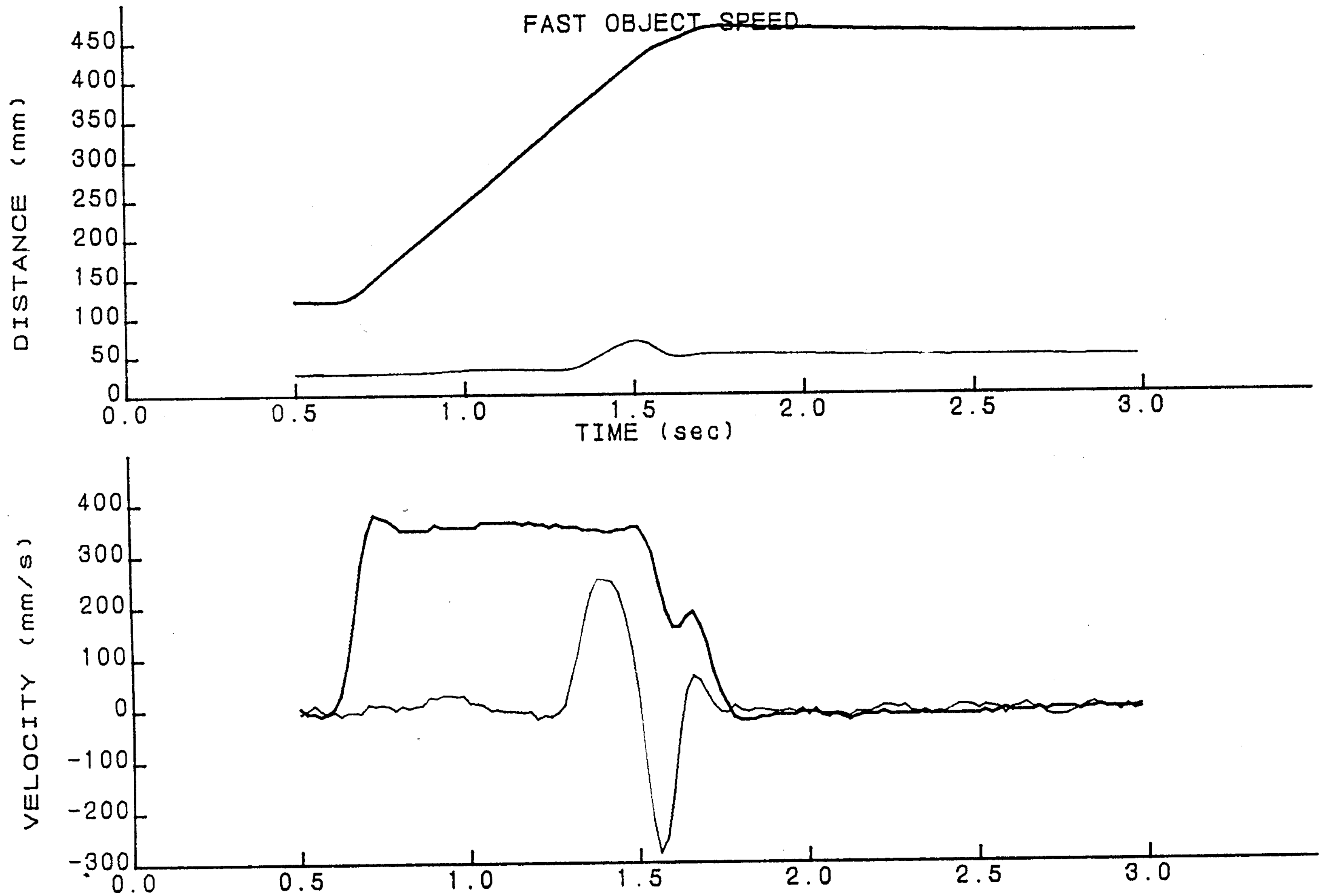

SLOW OBJECT SPEED
DISTANCE (mm)
450
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
TIME (sec)
VELOCITY (mm/s)
400
300
200
100
0
-100
-200
-300
0.0
0.5
1.0
1.5
2.0
2.5
3.0

FIGURE 3



FAST OBJECT SPEED
DISTANCE (mm)
450
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
TIME (sec)
VELOCITY (mm/s)
400
300
200
100
0
-100
-200
-300
0.0
0.5
1.0
1.5
2.0
2.5
3.0

FIGURE 4

FINGER-THUMB MOVEMENT TIME WITH AVERAGE WITHIN-SUBJECT SD

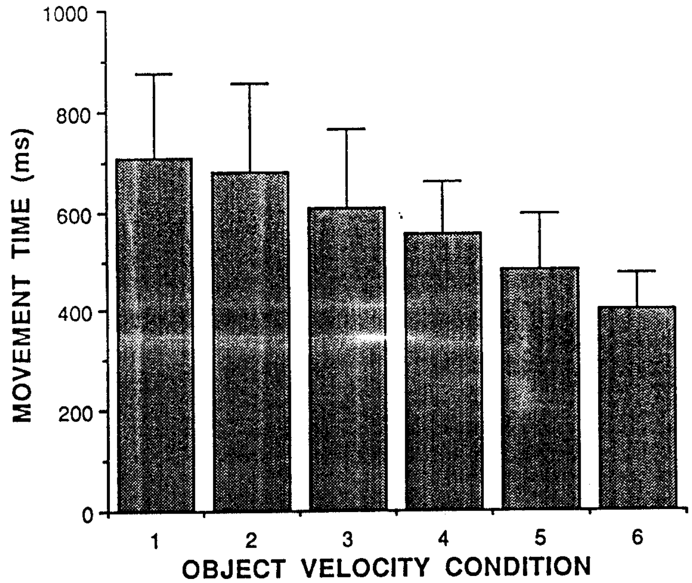


FIGURE 5

APERTURE SIZE AT FINAL CLOSING WITH AVERAGE WITHIN-SUBJECT SD

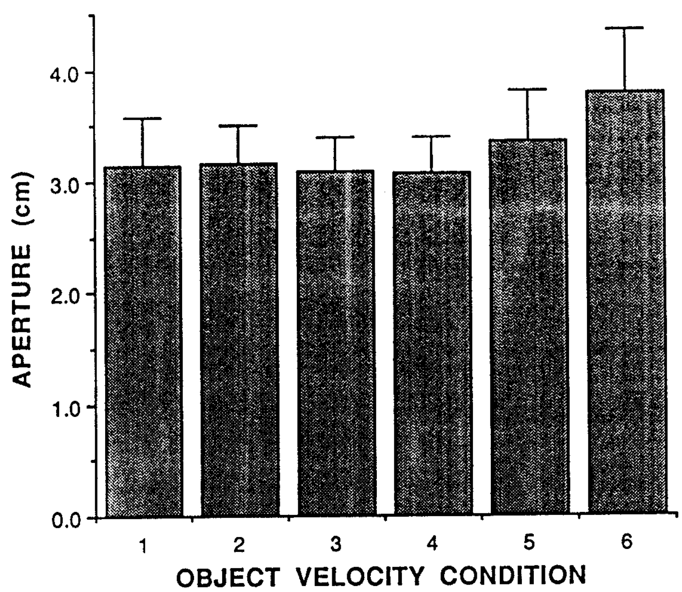


FIGURE 6

DISTANCE FROM HAND AT OPENING WITH AVERAGE WITHIN-SUBJECT SD

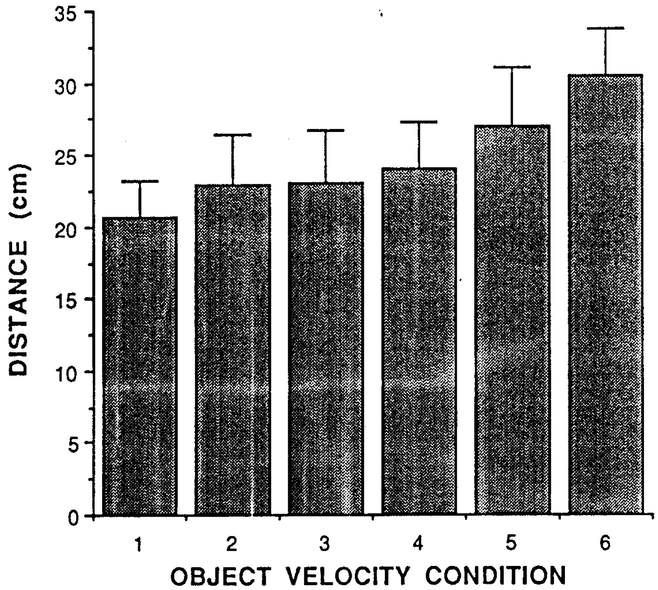


FIGURE 7

DISTANCE OF DOWEL FROM HAND AT INITIATION OF CLOSING WITH AVERAGE WITHIN-SUBJECT SD

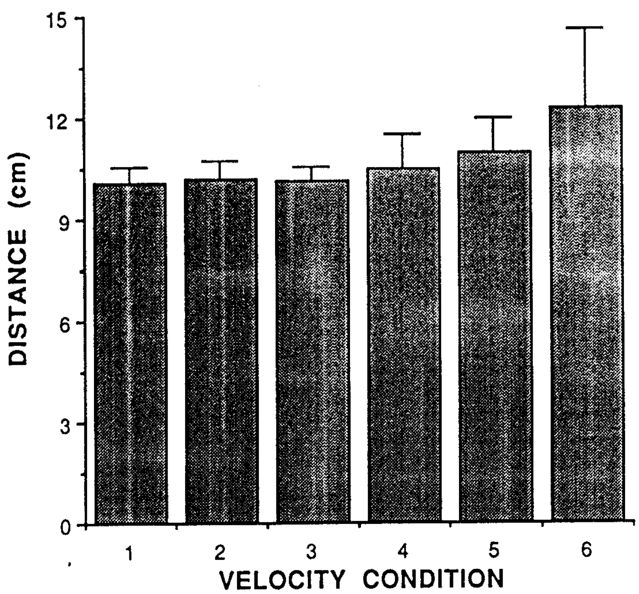


FIGURE 8

TAU AT HAND OPENING WITH AVERAGE WITHIN-SUBJECT SD

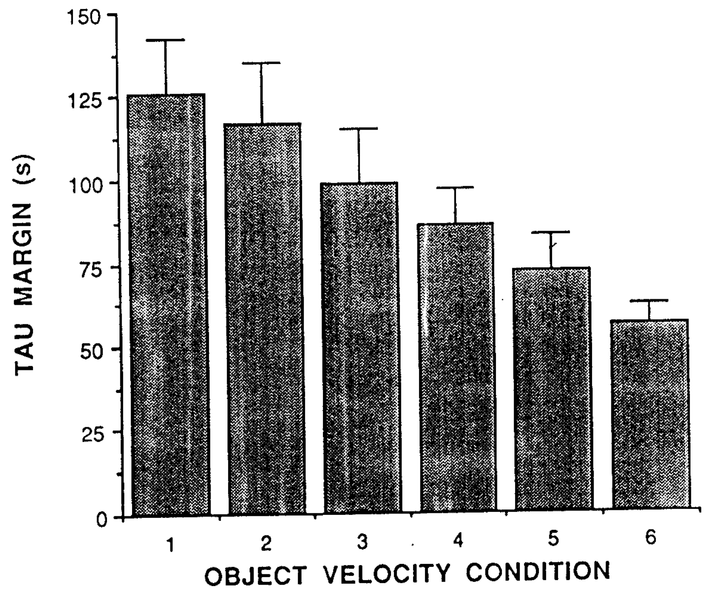


FIGURE 9

TAU AT INITIATION OF HAND CLOSING WITH AVERAGE WITHIN-SUBJECT SD

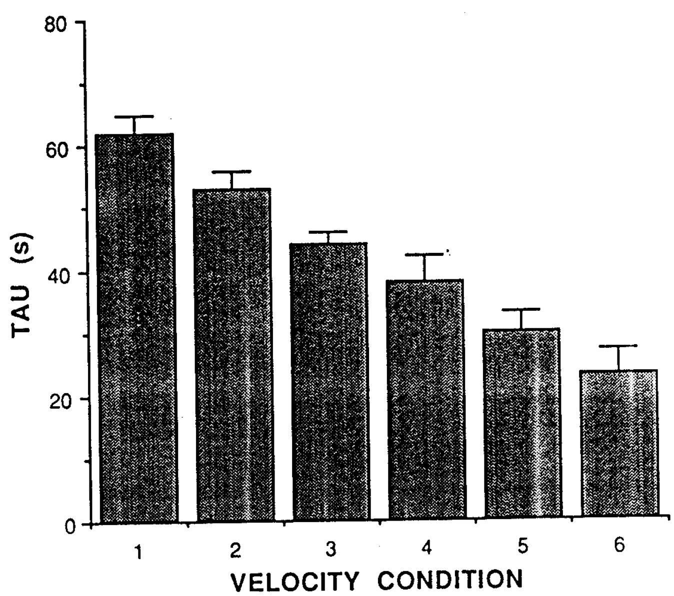


FIGURE 10

CORRELATION OF MT AND TAU MARGIN WITHIN VELOCITY CONDITIONS FOR EACH SUBJECT

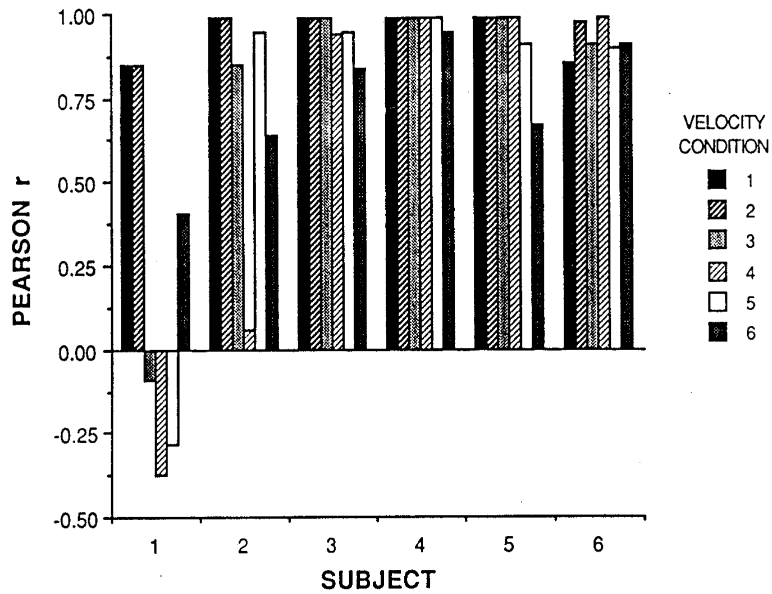


FIGURE 11

PERCENT TIME TO HAND OPENING WITH AVERAGE WITHIN-SUBJECT SD

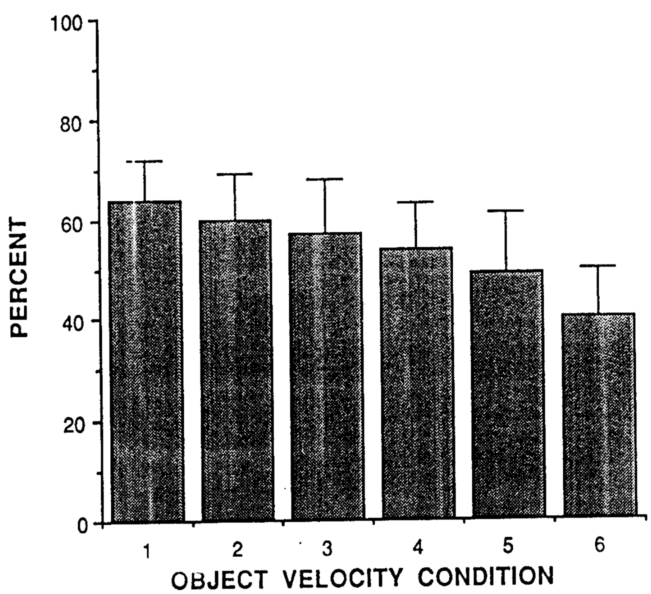


FIGURE 12

PERCENT TIME TO CLOSING WITH AVERAGE WITHIN-SUBJECT SD