Age Differences on a Coincident Anticipation Task: influence of Stereotypic or "Preferred" Movement Speed

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Abstract:
Two experiments were performed as an initial attempt to explain age related limitations in response accuracy on a coincident anticipation task. Five- to 9-year-old boys and adult males participated in each experiment. They made horizontal arm movements in response to stimuli from a Bassin Anticipation Timer. The results of Experiment I confirmed the findings of previous studies, which showed that young children respond early to slow moving stimuli. They were most accurate at intermediate speeds; their responses deteriorated as speed was increased. Older children and adults were more accurate at slow to intermediate speeds; their performances also declined at fast stimulus velocities. Experiment II examined use of a stereotypic or default movement speed as an explanation for these results, particularly for young children. A most comfortable movement pace was determined for each subject and was used as a baseline speed for a subsequent timing task. Four other stimuli were selected in 0.8 mph increments from the baseline speed (two faster, two slower). In addition, selected trials for 6 subjects at each age were filmed at 32 fps. *X*-coordinates for these trials were obtained and smoothed at 5 Hz. Movement time data suggested that 5-year-olds used a preferred or stereotypic speed, since they were accurate only when responding to their baseline speed. Older subjects matched stimuli up to and including their baselines. Kinematic characteristics confirmed the general notion of preferred speed for 5-year-olds. These same measures demonstrated that older subjects were increasingly adaptable in their responses, despite a failure to respond more accurately. Consequently, the term "preferred speed" lacks generality as an explanatory concept. Age-related shifts in the ability to modify components of a response, like average movement velocity and number of corrections, were used to explain accuracy differences.

Article:

Successful performance of many physical skills relies on intercepting an object as it travels through space: The squash player must anticipate how a ball will ricochet off a wall; the softball player must predict where a fly ball will go. Both players then must move to the appropriate spot. This process of adjusting a motor response to the arrival of an object at a specific time and place is called coincidence, or coincident anticipation (Belisle, 1963).

Although adult anticipatory responses have been examined extensively (e.g., Gerhard, 1959; Poulton, 1957), the study of age differences in the timing of motor actions is a relatively recent area of interest to motor development researchers. Available, developmental, timing research has primarily described the age-related improvements in accuracy that occur across a variety of tasks and stimulus speeds. There has been little attempt to explain how or why the observed age differences occur.

The pattern of these differences is robust across a wide range of stimulus speeds (Haywood, 1977; Shea, Krampitz, Northam, & Ashby, 1982); Stadulis, 1971; Wade, 1980): At slow speeds, young children (around 5-6 years) make their response or arrive at the target point very early (well before the stimulus). At "intermediate" speeds, these children are most accurate in their responses. Stimuli traveling faster than several miles per hour, however, result in responses that are made or concluded progressively later (after the stimulus arrives). Older children, around 8— 9 years, are more accurate than 5-year-olds at all speeds, particularly when a stimulus is slow to intermediately paced. Performances by 8- or 9-year-olds become increasingly less accurate as stimuli move faster. Adults are most accurate on these timing tasks, especially at slow to intermediate speeds, although their response accuracy also decrease' faster speeds.

Many different anticipatory tasks have been tested by investigators tasks as simple as a button push (Haywood, 1977) or as complex as running to anticipate where a projected ball will land (Williams, 1967). When difficult tasks are compared, only the magnitude of the error score changes. For example, Haywood (1977) had subjects perform separate button pushing and arm reaching tasks. While her youngest subjects responded early to both tasks, they were earlier on the simpler, button push task.

Speed differences in information processing have been offered as an explanation for children's inaccurate responses to timing tasks (Shea et al., 1982), since research has demonstrated that children do process information more slowly than adults (Chi, 1977; Gallagher & Thomas 1980; Thomas, 1980). For example, Gallagher and Thomas (1980) tested 7- and 11-year-olds on a nontiming, movement-accuracy task. When the youngest children had only 3 s to process knowledge of results, they were less accurate than the older subjects. When they had 12 s, the performed as well as 11-year-olds and adults. Speed of processing differences, where subjects have insufficient time to process incoming stimulus information and also respond accurately, could account for age differences in coincident anticipation accuracy at fast velocities. However, information processing theory does not explain performances by young children at slow speeds. At slow stimulus speeds, children should be most successful at arriving coincident with a moving stimulus. Instead, slowing the stimulus down (to increase the overall processing time) has resulted in children's responses that were progressively earlier in arrival at the target than the slow moving stimulus (Haywood, 1977; Shea et al., 1982). Investigators largely have ignored this discrepancy between theory and results in their attempts to explain the development of coincident anticipation behavior (Shea et al., 1982).

The two experiments that follow were performed as initial attempts to explain the pattern of age-related differences described for coincident anticipation studies. It was hypothesized that children (and possibly adults) resort to using a stereotypic, "default" response speed when task demands exceed their ability to process information adequately. Younger Children may have only this one-movement speed to fall back upon, while older children and adults have a larger repertoire with which to adapt to changing stimulus speeds. These older subjects "default" to their stereotypic-movement speed only when stimuli move too fast for them to adjust adequately.

Experiment I was performed to verify the results of a study by Shea et al., (1982). Their paradigm was replicated, since they used information processing speed differences to explain their results. The inconsistencies slow speeds noted previously were apparent in their data. In this replication, preliminary information was gathered comparing responses of children and adults.

Experiment II looked more specifically at the possibility that subjects, especially young children, resorted to use of stereotypic movement speeds. In this experiment, stimulus speeds were selected for each subject, based on a personal, self-chosen movement pace. Responses to a stimulus traveling at a personally chosen pace were hypothesized to be more accurate than to an arbitrarily chosen, "intermediate" stimulus speed. Selected trials for some subjects were filmed at high speed, so that comparisons of the kinematic characteristics of responses could be made. Examination of the kinematics of the movement made it possible to gather additional information about how responses were being performed.

EXPERIMENT

Method

Subjects

Three groups of right-handed boys, aged 5 (*M* = 69.1 months, *SD* = 3.3), 7 (*M* = 88.9 months, *SD* = 4.0), and 9 years (*M* = 116.9 months; *SD* = 5.2) participated in this experiment (*n* = 14 per group). A fourth group, of 14 male adults (*M* = 20.9 years, *SD* = 0.79), also took part.

Parental or individual permission was secured for each subject. Children were recruited from three elementary schools in Madison, Wisconsin; the adults were recruited from physical education major and general college activity classes at the University of Wisconsin-Madison.

Instrumentation and Experimental Task

A Bassin Stimulus Runway (Lafayette Instruments #5057513) and companion Anticipation Timer (Lafayette Instruments #50575A) were modified[1] for use in this experiment. A single runway section of the Bassin (67.5 cm in length), consisting of 16 apparently moving LEDs, was oriented horizontally so that the lights (4.5 cm apart) "moved" from left to right. A frame was fitted over the runway, suspending two microswitches vertically at a height of 10cm. The first ("start") microswitch was in line with the first LED; the second ("stop") rnicroswitch was in line with the final LED. The second switch was covered with a 2 × 8 cm padded "target." The light sequence was initiated when the first microswitch was released. Timing errors were displayed (in ms) when the second switch was closed. The conventional designation for early (—) and late (+) responses was used for scoring each trial.

Each subject was tested individually during a single 30 min session. Adults were seated at the center of the runway during testing; children stood at the same place. The height of each subject's arm and his distance from the apparatus was adjusted so that a free and unimpeded movement could be made. This adjustment was necessary to insure a clear view of the runway lights throughout each trial. The starting position for each trial was with the right hand across the midline, depressing the "start" microswitch. Subjects released the switch to initiate a trial and made a "backhanded", horizontal arm movement from left to right that ended when contact was made with the second switch. The goal was to time the movement so that the "stop" microswitch was closed coincident with the lighting of the final LED. No specific movement cues were given to subjects about how they should respond, since their solution to the movement problem was of interest. Each subject was given five practice trials, using speeds other than those actually tested.

Sixty test trials were administered to each subject. Ten trials, each, of six different stimulus velocities, were ordered randomly and given in two blocks of 30 trials. The stimuli were: 1.5 mph (67.1 cm/s), 2.0 mph (89.4 cm/s), 2.5 mph (111.8 cm/s), 3.0 mph (134.1 cm/s), 3.5 mph (156. cm/s), and 4,0 mph (178.8 cm/s). The intertrial interval was 5 s. The rest period between blocks was approximately 10 min.

Design

The raw data from this experiment were converted to three dependent measures: constant (signed) errors, absolute (unsigned) errors, and arm movement times. Arm movement time refers to the average time subjects took to move between the microswitches, averaged for a given stimulus. Separate simple effects (nested) analyses of variance were performed on each data set (Maraschilo & Levin, 1970). Scheffé post hoc tests were performed on comparisons of interest.

Each of the two-way ANOVAs was performed at $\alpha = .01$. Post-hoc comparisons were tested at $\alpha = .01$. Trials effects were examined initially in a three-way ANOVA at a = .001 (Actual *ps* will also be reported for all tests).

The trials effects on constant errors were examined in an age (4) × velocity (6) × trials (10) simple effects ANOVA, with repeated measures on the final two factors. This preliminary analysis was necessary since Haywood and her colleagues (Haywood, Greenwald, & Lewis, 1981) found that responses to one stimulus could be directionally biased by a previous stimulus of a different speed, particularly when slow velocities were involved. The trial × age interactions were tested in an analysis with ages and trials nested in velocities. All of the interactions were nonsignificant: at 1.5 mph, $F_{27,468} = 1.96$, $p = .003$; at 2.0 mph, $F_{27,468} = 2.00$, $p = .002$; at 2.5 mph, $F_{27,468} = 1.65$, $p = .023$; at 3.0 mph, $F_{27,468} = .76$, $p = .81$; at 3.5 mph, $F_{27,468} = .84$, $p = .70$; at 4.0 mph, $F_{27,468} = 1.02$, $p = .44$.

The trial × age interaction approached significance at 1.5 and 2.0 mph. The across-trials data for each age group were visually examined for these two stimuli. Five- and 7-year-olds were more variable from trial to trial than their older counterparts. Their variability was the likely cause of the higher levels of significance. Since there was no systematic increase or decrease in the size of the constant errors to 1.5 and 2.0 mph, trials were collapsed within these and all other stimulus velocities for the remaining analyses.

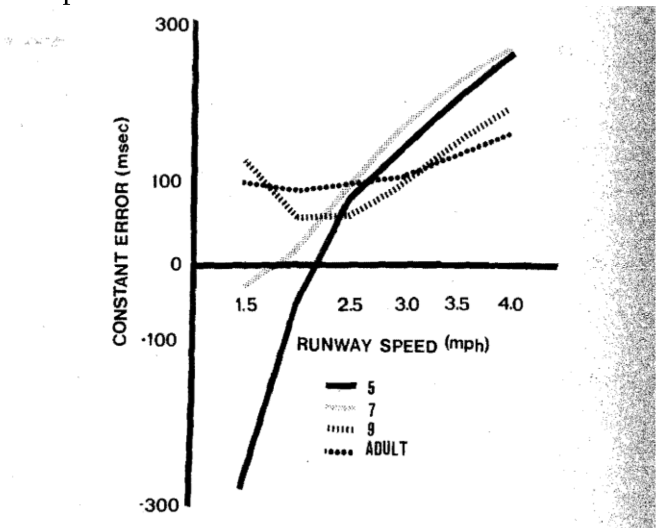

Fig. 1—Constant errors (in ms) for 5-, 7-, and 9-year-old boys and adult males responding to stimuli traveling between 1.5–4.0 mph.

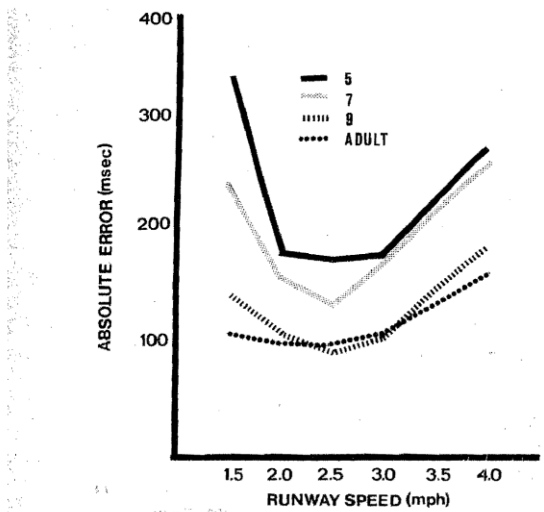

Fig. 2—Absolute errors (in ms) for 5-, 7-, and 9-year-old boys and adult males responding to stimuli traveling between 1.5–4.0 mph.

Results

Constant Errors (CE)

A simple effects ANOVA, with age (4) nested in velocity (6), was performed on signed errors. Age differences were significant within 1.5 mph, 2.0 mph, 3.5 mph, and 4.0 mph: $F_{3,52} = 32.53$, $p = .00001$; $F_{3,52} = 5.00$, p .004; $F_{3,52} = 4.30$, $p = .009$; $F_{3,52} = 6.60$, $p = 0007$, respectively.

As shown in Figure 1, 5-year-olds' accuracy differed from all other subjects at 1.5 mph. Scheffé post hoc comparisons also showed that only 5-year-olds and adults differed in their accuracy at 2.0 mph. At 3.5 and 4.0 mph, older subjects were more accurate than younger children (5- and 7-year-olds). No other paired comparisons were significant.

Absolute Errors (AE)

Absolute errors were examined in a simple effects ANOVA, with age (4) nested in velocity (6). There were significant age differences within each stimulus velocity: at 1.5 mph, $F_{3,52} = 29.50$, $p = .00001$; at 2.0 mph, $F_{3,52}= 10.69$, $p = .0001$; at 2.5 mph, $F_{3,52} = 5.94$, $p = .0015$; t 3,0 mph, $F_{3,52} = 5.05$, $p = .004$; at 3.5 mph, $F_{3,52} = 6.29$, $p = .001$; at 4.0 mph, $F_{3,52} = 7.98$, $p = .0002$.

At 1.5 mph, 5-year-olds had larger absolute errors than any other age group (Figure 2). In addition, 7-year-olds were less accurate than either 9-year-olds or adults. Younger subjects (5- and 7-year-olds) had larger errors than older subjects (9-year-olds and adults) when stimuli traveled from 2.0-4.0 mph.

Arm Movement Times

Arm movement times were computed by adding a constant to each subject's signed errors. These constants were the actual times (in ms) required for the lights to move down the runway (runway times): 1006 (1.5 mph), 755 (2.0 mph), 604 (2.5 mph), 503 (3.0 mph), 431 (3.5 mph), and 378 (4.0 mph).

To analyze subjects' arm movement times in response to the six stimuli, a simple effects ANOVA, with velocity (6) nested in age (4), was performed. Significant *F* values occurred for all age groups: 5 years, $F_{5,260} = 8.38$, p = .00001; 7 years, $F_{5,260} = 89.07$, p = .00001; 9 years, $F_{5,260} = 269.33$, *p* = .00001; adults, $F_{5,260} = 260.05$, p = .00001. The movement time of the 5-year-olds at 1.5 mph differed from those 3.0-4.0 mph (Figure 3). No other significant differences were found for the youngest children. The 7-year-olds' movement time at 1.5 mph differed from all others; the time they took at 2.0 mph differed from the time at 3.0-4.0 mph. As shown in Figure 3, 9-year-olds had unique movement times at 1.5 and 2.0 mph. Their average time at 2.5 mph also differed with times at 3.5 and 4.0 mph. Adults had different movement times for responses to all but the two fastest stimuli (3.5 and 4.0 mph).

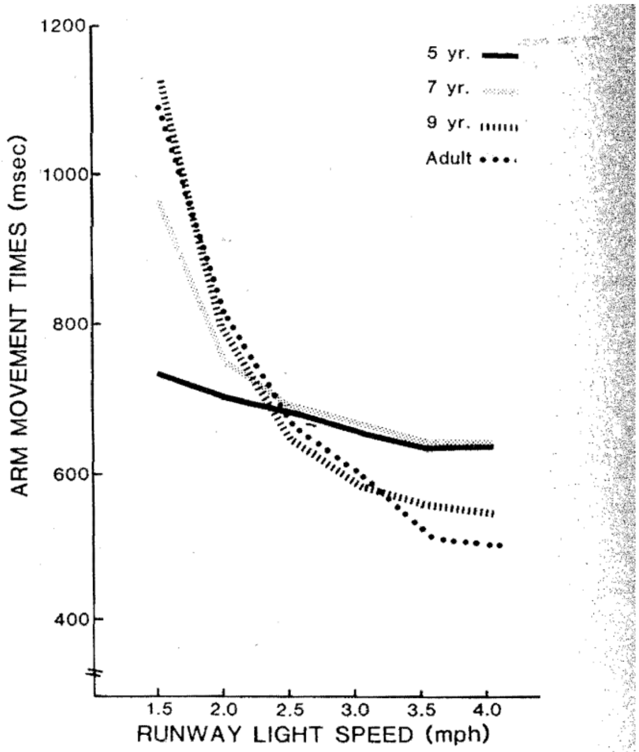

Fig. 3—Arm movement times (in ms) for 5-, 7-, and 9-year-old boys and adult males responding to stimuli traveling between 1.5–4.0 mph.

To examine movement time consistency across the six stimuli, separate random model ANOVAs were performed on the movement time data for each age group. Percentage of variance estimates were computed for each factor within each ANOVA (Table 1). As shown in Table 1, the variance accounted for by between-subject differences decreased across age, from 78.9% in the 5-year-olds and 25.2% in the 7-year-olds, to 1.4% in 9-year-olds and 2.7% in adults. At the same time, the variance accounted for by responses to different stimulus velocities increased dramatically. In the 5-year-olds, the velocities variance was only 6.6% of the total; in the 7-year-olds, it was 54.6% of the total variance. For the 9-year-olds and adults, this same variance component accounted for over 96% of the total.

Discussion

The pattern of results found in this experiment replicated previous (Shea et al., 1982) findings for a simple arm movement timing task, For CE (Figure 1), 5-year-olds finished their responses early to slow moving stimuli; they were late when stimuli traveled fast. Their movements were most accurate at intermediate stimulus speeds. Older children and adults were more accurate than 5-year-olds overall, particularly in response to slow moving stimuli. Their errors increased when they responded to faster moving stimuli. Shea's results, also, were replicated for AE (Figure 2), where error magnitudes were inversely related to age.

Information Processing and Stereotypic Movement *Speeds*

Based on information processing notions, Shea et al. (1982) hypothesized that if a stimulus were slowed down sufficiently, age differences would become minimal. The results of the present experiment demonstrated that giving slower moving stimuli (and increasing overall response time) did not improve young children's accuracy.

In fact, consistent with Shea et al.'s (1982) findings, 5-year-olds' accuracy at 1.5 mph was dramatically poorer relative to performances at 2.0 and 2.5 mph (Figures 1 & 2). Despite some modification in movement speed by 5-year-olds at 1.5 mph, information processing cannot fully explain age differences in performance on timing tasks, particularly at slow stimulus velocities.

Table 1
Percentage of Variance Estimates for Each Age Group Across Stimulus Velocities

	Variance Component		
Age	Subjects	Velocities	S x V[a]
5	78.9[b]	6.6	14.4
7	25.2	54.6	20.2
9	1.4	96.4	2.1
Adult	2.7	96.3	1.0

[a] S x V refers to the subject × velocity interaction, or error term.
[b] All entries are in percentages.

One reason the 5-year-olds may have performed poorly at certain speeds was because they rarely changed their arm movement speed. At 2.0 mph and above, these children always had the same response time (Figure 3). Since response times can be translated directly to movement speed, these children clearly used a stereotypic response speed in relation to stimuli faster than 1.5 mph. Five-year-olds only slowed down in response to the slowest moving stimulus. Even at 1.5 mph, the amount of adaptation was minimal, and was insufficient to markedly improve their accuracy (Figures 1 & 2).

Examination of the percentage of variance attributed to stimulus velocities demonstrated further that these 5-year-olds used a stereotypic response time or movement speed in relation to most stimuli. A negligible amount of the variance was accounted for by the velocity component (6.6%), while subject differences contributed 78.9% of the variance, demonstrating that individual differences in subjects' response times accounted for the greatest amount of the variance. Simultaneously, children's responses across the stimuli were very consistent. Apparently, the speed of the stimulus made little difference to these young children.

Older children were less consistent than the 5-year-olds in the response time they used across stimulus velocities, although individual differences remained (Table 1). In the 7-year-olds, nearly 55% of the variance was accounted for by the velocity component, suggesting that they changed their response time or movement speed in relation to some stimuli. Figure 3 shows changes in the response time used by 7-year-old children at slow stimulus speeds. These children slowed their arm speed in response to stimuli moving at 1.5 mph. Their adaptation to faster moving stimuli was less clear.

For 9-year-olds and adults, the velocity component accounted for most of the variance (around 96%), suggesting that they modified their movement speed to a wide range stimuli. As shown in Figure 3, these subjects changed their response times to all but the fastest moving stimuli (3.5— 4.0 mph). Older subjects apparently "defaulted" to a stereotypic speed when they could not respond accurately. In contrast, the small amount of subject variance for 9-year-olds and adults (1.4 and 2.7%, respectively), demonstrates that there were inconsequential individual differences in their responses.

Since response times averaged across the whole movement have been analyzed, children's use of a stereotypic response speed is speculative and requires further study. A data analysis by Shea et al. (1982) supports this explanation. Those investigators divided the Bassin runway into six equal segments. Movement times were recorded for each segment, to determine where (and if) subjects modified their movement speed when stimuli traveled at different velocities. Results showed that 5-year-olds' only changed their speed in response to the slowest stimulus, and that the movement was two-thirds completed when this change was made. At other velocities, they used a single movement speed. The 9-year-olds tested by Shea et al. (1982) changed their movement speed by the time the response was half completed. They too resorted to using a stereotypic movement speed at the fastest velocities. For most stimuli, adults modified their speed when the movement was one-third completed, but used a stereotypic response at 3.5-4.0 mph.

The present experiment and Shea's study demonstrated that subjects of all ages tested used stereotypic or “default” movement speeds under certain conditions. Young children used this speed nearly all the time) older subjects resorted to it as necessary.

EXPERIMENT II

Method

Based on the results of Experiment I, it was hypothesized that subjects of all ages would match a stimulus' speed most closely if it traveled at a self-chosen, or most comfortable pace. Instead of being "most accurate" at some arbitrarily chosen, intermediate speed, subjects would be able to match a stimulus traveling at their own, predetermined arm movement speed. Young children in Experiment I apparently used this single arm speed to respond to a range of stimuli. Therefore, when stimuli traveled at speeds other than their self-chosen pace, they would be inaccurate. Older children would be able to modify their responses to stimuli up to and including their self-chosen pace. They would resort, or "default" to their self-chosen speed when stimuli moved faster. Adults would be most adaptable, and therefore, most accurate, across the widest range of stimulus speeds.

Subjects

Three groups of 5 (*M* = 69.9 months, *SD* = 3.3), 7 (*M* = 911 months, *SD* = 4.5) and 9-year-olds (*M* = 118.2 months, *SD* = 3.6) participated in the second experiment. There were 14 children in each of the 5- and 9-year-old groups and 15 children in the 7-year-old group. In addition, a small group of adults (*n* = 10, *M* age = 24.3 years; *SD* = 5.7 years) were tested. None of these subjects had taken part in Experiment I.

All subjects were volunteers. The children were recruited from a single elementary school in Madison, Wisconsin. The adults were from physical education major and general college activity classes at the University of Oklahoma in Norman, Oklahoma.

Experimental Task and Instrumentation

This experiment required two testing sessions held on separate days. The entire procedure took 30-40 min per subject. During the first session, an individual's self-chosen movement speed was estimated from 30 trials of a horizontal arm movement like that used in Experiment I. Subjects were asked to move between the microswitches using a "comfortable pace." Only the final 21 trials were averaged to estimate arm speed since previous studies (Smoll, 1975a, 1975b) showed that subjects changed their movement speed during initial trials as they adjusted to the task.

Subject's self-generated speeds were used as baseline stimulus velocities for a timing task performed during the second testing session. Four additional stimulus velocities were computed for each individual by incrementing and decrementing the baseline speed in 0.8 mph intervals. Ideally, subjects would respond to two stimuli faster and two stimuli slower than their baselines. For example, if a subject's self-chosen speed was 2.1 mph, two slower speeds (1.3 and 0.5 mph) and two faster speeds (2.9 and 3.7 mph) were specified. A cut-off point of 0.4 mph was selected, below which no stimuli could fall. This cut-off resulted in some subjects responding to 3 or 4 stimuli traveling faster than their baseline. Ten trials each, of the 5 stimulus velocities, were administered to each subject. Trials were given randomly in two blocks of 25 trials, with a 2 min rest between blocks, The procedures of this part of the testing were the same as in Experiment I.

The Bassin apparatus used in Experiment I was modified for the initial testing session. The runway portion of the apparatus was covered, so that the lights would not distract subjects as their self-chosen movement speeds were estimated. Runway time was set at 425 ms, allowing average arm movement times to be computed as in Experiment I. During the second part of testing, the Bassin timer was used as described in Experiment I.

In addition, during the second testing session, selected trials from 6 subjects in each age group were filmed. Two trials of each stimulus velocity were chosen randomly prior to testing. Trials were filmed using a 16 mm motor-driven, Photo-sonics (Model 1VN), or Milliken (Model DBM-5) camera placed 15 feet from the experimental apparatus, and perpendicular to its frontal plane. This orientation afforded an unobstructed view of the subject's hand throughout each response. Film speed was 32 fps. Subjects who were filmed wore a black and white marker on the index finger of their right hand to provide a clear indication of the path of the hand's movement during responses.

Movement Time Analyses

If subjects moved at their baseline, or most comfortable speed when performing the timing task, their errors would most closely approach zero (response time or arm movement time would equal runway time) when the stimulus velocity matched their baseline speed. Case by case comparisons between arm movement speed and runway time were made, since subjects responded to personalized stimuli. A non-parametric, Wilcoxin signed rank test for matched pairs was selected for this analysis. Each age group was analyzed separately. Each test was performed with a as close to .01 as possible. Alpha values varied somewhat with cell sizes, however, since non-parametric tests are exact tests.

In addition, arm movement times were analyzed in a simple effects ANOVA ($\alpha = .01$). Scheffé post hoc tests ($\alpha = .01$) were performed to examine whether subjects used different average movement times in response to stimuli traveling at different velocities.

Kinematic Analyses

A PCD Digital Data Reader, interfaced with a Cromemco computer, was used to obtain *x* coordinates for frame-by-frame positions of the tip of subjects' right index finger. Previous research (Salmoni, 1983) suggests that for horizontal movements, combined use of *x* and *y* coordinates adds little information over the *x* value alone. Thus, our coordinate data were smoothed using a digital filter cut-off frequency of 5 Hz. Derived velocities and accelerations were similarly smoothed.

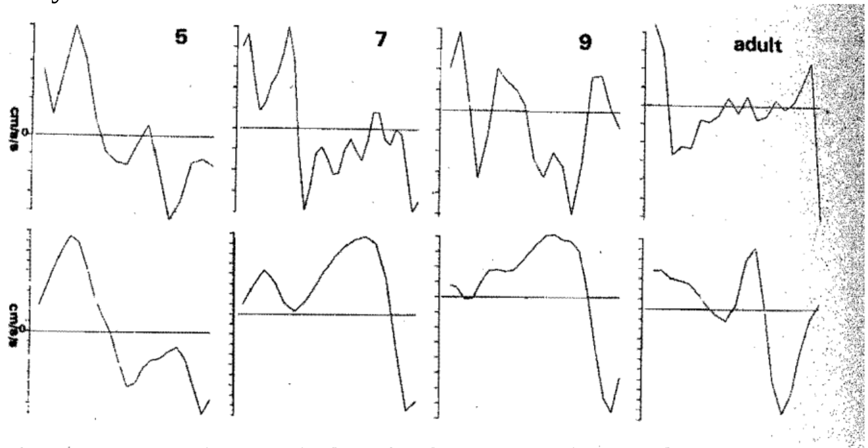

Fig. 4—Representative smoothed acceleration curves for horizontal arm movements made by 5(far left)-, 7(center left)-, 9(center right)-year-olds and adults (far right). Top row represents responses to stimuli less than 2 mph; bottom row curves are from stimulus speeds 2 mph or faster.

Examination of several kinematic parameters was suggested from previous investigations (Salmoni, 1983; Schellekens, Kalverboer, & Scholten, 1984) of rapid, aiming movements. Subjects performing these accuracy movements typically begin their responses with a ballistic, distance covering phase and finish with a series of one or more corrections, which enable them to "home in" on the target. These distance-covering (DC) and homing (HOM) phases are derived from smoothed acceleration curves (Figure 4). Typically, the DC element is defined as an initial acceleration/deceleration phase (Schellekens et al., 1984). Subsequent phases (elements) of acceleration/deceleration constitute the homing portion of a response. These definitions were accepted for the purposes of this investigation, with one exception. In a small percentage of trials, subjects initiated their responses with a phase of deceleration, followed by an initial acceleration. This difference in the DC element from previous studies can be attributed to the different purpose of the present movement. Movements examined by Salrnoni (1983) and Schellekens et al. (1984) were to be made as quickly and as spatially accurate as possible. In contrast, subjects in the present study were to modify their arm speed to match the stimulus' speed. Temporal, rather than spatial accuracy, was important. The initial phase of deceleration may represent a strategy used by some subjects as they attempted to increase their timing accuracy. They apparently released the first microswitch and then waited briefly while trying to determine the stimulus' speed. The percentage of trials where this pattern was observed increased across age (8% in 5- to 7-year-olds vs. 19% in 9-year-olds and adults), suggesting that it might represent a strategy used by older subjects. Therefore, for these analyses, an initial phase of acceleration/deceleration or deceleration alone was considered to be the distance-covering portion of a response.

Once each response was divided into these two general phases of the movement, several additional measures could be derived for comparison across age and stimulus velocity: (a) total number of elements (complete phases of acceleration/deceleration, regardless of assumed purpose—DC or HOM); (b) duration of each phase; and (c) average movement velocity of each phase.

Results

Selection of Stimulus Velocities

Across all subjects, self-chosen movement speeds ranged between 0.7-8.2 mph. Average arm speeds used by 5-year-olds ranged from 1.5– 4.7 mph (*M* = 2.2; *SD* = 0.8); for 7-year-olds, the range was 0.9-,7.3 mph (*M* = 2.6; *SD* = 1.7) For 9 year olds, the range of arm movement speeds was 0.7-8.2 mph (*M* = 2.4; SD = 1.7). Adults' movement speeds ranged from between 0.7-7.6 mph (*M* = 3.9; *SD* = 1.7).

Arm Movement Times and Self-Chosen Speeds

As shown in Figure 5 (upper left), 5-year-olds' arm movement time matched runway times only at the baseline (designated 0 in the Figure), When the stimulus was slow (high runway time), they moved too quickly; when the stimulus was fast (low runway time), they went too slowly. Seven- and nine-year-olds (Figure 5, upper right and lower left panels, respectively) were accurate at speeds up to and including their baselines. For stimuli traveling faster than the baseline speed, both groups of older children also moved slower than the runway lights (Figure 5). Finally adults (lower right) matched movement and runway speeds only for their slowest stimulus. When stimuli traveled faster, they moved too slowly relative to the lights.

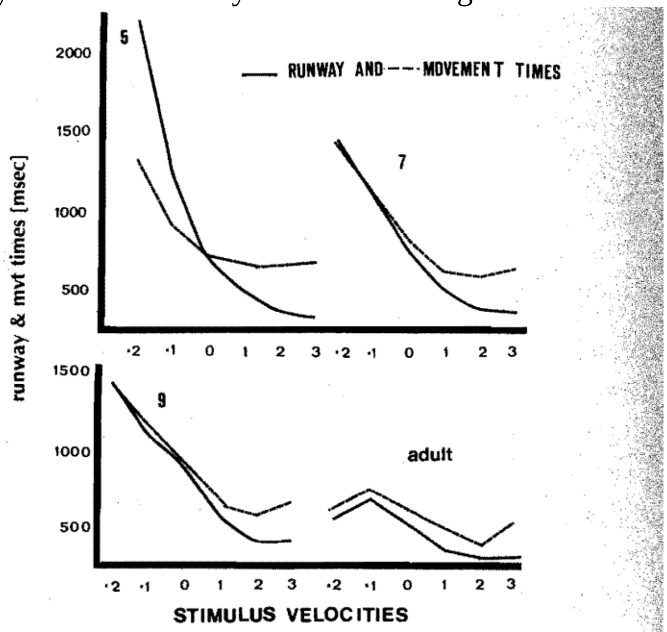

Fig. 5—Comparisons of runway and movement times for 5-year-olds (upper left), 7-year-olds (upper right), 9-year-olds (lower left), and adults (lower right) for stimulus velocities averaged relative to baseline preferred speeds (0). Stimuli are incremented (+1, +2) and decremented (−1, −2) in 0.8 mph units from the baseline.

The Wilcoxin analysis yielded some unexpected, significant results. A marginally significant difference (p = .009) occurred at the 7-year-olds' baseline speed. The actual difference between runway and movement times at that speed was small (upper right panel, Figure 5). This finding of significance may be an artifact of the Wilcoxin test statistic which is based on the sum of the positive ranked differences between matched pairs. For these data, differences were typically positive, although small leading possibly to a spurious result.

More surprising were the results from the adults' data analysis. It wa^s expected that adults would be better than the children at matching their movement speeds with runway speeds. Clearly this was not the case (Figure 5, lower right). Positive constant errors may have contributed to the significant finding for all but the slowest moving stimulus. That adults generally selected faster stimulus speeds than any other group was the more likely cause. Adults in this study selected movement speeds that averaged more than 1 mph faster than children of any age. Adults may have had insufficient time to process stimulus information and still respond accurately given these faster runway speeds.

To determine what response time subjects used in relation to each stimulus, a simple effects ANOVA, with velocity (5) nested in age (3) was performed. In order to solve the problem of small cell sizes for the extreme stimuli, they were arranged from slowest to fastest, without regard to the location of an individual's baseline. The pattern of response times was unchanged when this procedure was used.

These movement time data were tested ($\alpha = .01$) using Geisser-Greenhouse estimates. Conservative values were chosen, since the method used for selecting stimuli resulted in large *SD*s for movement times, presumably violating the homogeniety of variance assumption.

Five-year-olds modified their movement responses only in relation to their slowest stimulus velocity, $F_{1,50} = 6.49$, p = .013. For all other stimuli, they used one response time. The 7- and 9-year-olds used different movement times in response to several stimuli, $F_{1,50} = 26.03$, p = .00001; $F_{1,50} = 24.44$, *p* = .00001, respectively. These children used one response time or speed in relation to their slowest stimulus velocity. Paired comparisons between the second slowest stimulus velocity, and all others approached, but did not reach significance, for the 7- and 9-year-olds. No statistically significant differences were found among the adults' movement times, $F_{1,50} = 4.97$, p = .029, despite an apparent trend toward changing movement times relative to at least the two slowest moving stimuli.

Kinematic Data

A total of 214 trials were available for film analysis. This number included 48 trials for the 5-year-olds, 57 from amongst the 7-year-olds, 53 from the 9-year-olds, and 56 from the adults. Because each subject responded to his own personalized set of stimuli, only small numbers of trials were available at any single speed. In order to maintain a reasonably large number of trials within each cell, the data from this part of the experiment were divided into two groups: Responses to stimuli traveling less than 2,0 mph and responses to speeds greater than or equal to 2.0 mph. Based on the results from Experiment I and Shea et al. (1982), the slower group of stimuli represented responses where 5- to 7-yearolds might begin to modify their movements; faster stimulus velocities were those where little evidence of adaptation had been observed. This subdivision resulted in trials categorized as follows: 5-year-olds had 16 trials ranging from 0.6-1.7 mph (*M* = 1.3, *SD* = .37) and 32 trials between 2.0-4,5 mph (*M* = 3.2, *SD* = .8); 7-year-olds had 11 trials between 0.9-1.9 mph (*M* = 1.4 mph, *SD* = .4) and 46 trials from 2.0—5.9 mph (*M* = 3.6, *SD* = 1.0); 9-year-olds had 15 trials ranging from 0.5-1.6 mph (*M* = 1.1 mph, *SD* = .4) and 38 trials between 2.1-8.2 mph (*M* = 4.1, *SD* = 1.8); finally, adults had 7 trials whose speeds were 0.7-1.9 (*M* = 1.3, *SD* = .5) and 49 trials between 2.3-7.6 mph (*M* = 4.7, *SD* = 1.4). For stimuli faster than 2.0 mph, small cell sizes at one age or another prevented a finer-grained analysis.

Within and between age and stimulus velocity comparisons were made for each kinematic parameter. Most of these data were analyzed using repeated measures analyses of variance ($p < .01$). While an *a priori* alpha level of .01 was set, marginally significant tests ($p < .05$) will be reported due to the exploratory nature of this investigation. Post-hoc least , significant difference tests are reported ($p < .01$) for comparisons of interest.

Movement elements. No significant age differences were detected to$_r$ the number of elements used by subjects responding to slower moving stimuli, $F_{3,12} = .85$, p = .48. On the other hand, for the faster speed, 5-year-olds attempted more corrections than the adults, $F_{3,20} = 12.69$, *p* = .0001. When the numbers of elements were compared across stimulus velocities within each age group, marginal differences occurred for the 5-year-olds and adults. The 5-year-olds made slightly more corrections in their responses to faster stimuli, *M* = 2.0 for slower and 2.8 Tor faster stimuli; $F_{1,5}$ = 5.66, p = .022. On the other hand, adults made fewer corrections in relation to faster-moving stimuli, M = 3.24 and 1.78, respectively, $F_{1,5}$ = 6.46, p = .014. Differences for 7- and 9-yearolds did not approach significance, $F_{1,5}$ = 58, p = .45 and $F_{1,5}$ = .20, p = .65, respectively.

Distance-Covering Phase (DC). No significant differences were found within or between ages for the average velocity used during the initial, distance-covering segment of the response. Subjects of all ages began their responses at a consistent pace, regardless of stimulus speed. In contrast, significant differences occurred at all ages for the duration or the DC phase: 5s, $F_{1,5}$ = 26.41, p = .0001; 7s, $F_{1,5}$ = 46.48, p .0001; 9s, $F_{1,5}$ = 25.40, p = .0001; adults, $F_{1,5}$ = 11.44, p = .014. Although the difference was only marginal for the adults, all groups had a longer DC phase when responding to slow versus faster stimuli. No significant difference occurred between ages.

***Homing phase* (HOM).** When stimuli were 2 mph or faster, subject, at all four ages traveled faster during the homing phase of their response than when they responded to slower moving speeds: 5s, $F_{1,5}$ = 17.71, p = .0001; 7s, $F_{1,5}$ = 38.29, p = .0001; 9s, $F_{1,5}$ = 20.86, p = .0001; adults, $F_{1,5}$ = 16.03, p = .0002. Across-age comparisons were marginally significant: for < 2 mph, $F_{3,12}$ = 2.9, p = .04; for 2 mph, $F_{3,20}$ = 3.05, p = .03. At the slower speeds, 5-year-olds' homing velocity was faster than the adults; for the faster stimuli, 5- and 7-year-olds moved more slowly than the adults.

The duration of the homing phase differed between stimulus velocities for all groups except the 5-year-olds: 5s, $F_{1,5}$ = .44, p = .51; 7s, $F_{1,5}$ = 12.24, p .001; 9s, $F_{1,5}$ = 22.70, p = .0001; adults, $F_{1,5}$ = 21.98, p = .0001). All of the older subjects had a longer homing phase when they responded to slower stimuli.

Since the number of corrections made during a response is likely to impact the duration of the homing phase, Pearson product-moment correlations were computed for each age and stimulus velocity group. Five of the eight correlations ranged between .80—.95 (Table 2). Low trial-to-trial variability in number of corrections may have kept the remaining three correlations artificially low (Table 2).

Table 2
Pearson-Product Correlation, Means and Standard Deviations for Number of Movement Elements and Duration of Homing Phase of Responses

Age	Stimulus Velocity <2 mph	Stimulus Velocity ≧2 mph
5	.92*	.95*
M(*SD*) Elements	2.0(1.12)	2.8(1.5)
7	.66	.67*
M(*SD*) Elements	2.45 (.8)	2.3 (.8)
9	.92*	.89*
M(*SD*) Elements	3.1(2.4)	2.4(1.2)
Adult	.89*	.56*
M(*SD*) Elements	3.1(2.0)	1.8 (.7)

Note. All movement elements are included in this analysis, in order to maximize variability.
* $P < .01$.

Distance-covering/Homing phase Comparisons. In order to examine the hypothesis that some subjects used a preferred pace while making simple arm movements, it was necessary to compare variables *within* responses. Therefore, movement speed measured during the DC and HOM portions of responses was compared for both sets of stimulus velocities. In addition, the duration of each phase of the response was compared.

Five-year-olds used the same movement velocity during the DC and HOM part of their responses, regardless of stimulus velocity: $F_{1,5}$ = 3.54, p = .072 and $F_{1,5}$ = 2.37, p = .13 for slow and fast stimuli, respectively. In addition, the duration of each phase was the same for stimuli traveling less than 2 mph $F_{1,5}$ = .003, p = .96. The DC phase was longer than the correcting phase for faster stimuli, $F_{1,5}$ = 1334, p = .0006.

When 7-year-olds responded to stimuli of less than 2 mph, their velocities did not differ for the two parts of the movement, $F_{1,2} = 2.49$, p = .13. The homing phase was longer than the DC phase for those slower movements $F_{1,2} = 7.12$, p = .016. These children increased their movement velocity during the homing phase when stimuli were fast, $F_{1,5} = 17.58$, *p* = .0001. In addition, the correcting phase was longer than the DC phase for stimuli above 2 mph $F_{1,5} = 17.48$, p = .0001.

The tendency to respond differentially across the two parts of the movement continued with the oldest children. Although velocity differences were only marginally significant at slow stimulus speeds, $F_{1,4} = 4.78$, p = .039, the duration of the homing phase was considerably longer $F_{1,4} = 10.36$, *p* = .004. For stimuli faster than 2 mph the 9-year-olds traveled much faster during the longer homing phase $F_{1,5} = 11.67$, p = .001 and $F_{1,5} = 1\ 2.93$, *p* = .0006 for velocity and duration, respectively.

Finally, the adults slowed their velocity during the homing phase of their responses when stimuli traveled slower than 2 mph, $F_{1,1} = 13.93$, *p* = .003. Although the HOM phase was much longer than the DC phase, a lack of statistical power resulted in only a marginally significant finding, $F_{1,1} = 4.73$, p = .052. For stimuli traveling faster than 2 mph, the adults traveled much faster during the homing phase, $F_{1,5} = 29.98$, *p* = .0001; the relative duration of these phases was the same, however $F_{1,5} = .78$, *p* = .38.

Discussion

In this second experiment, evidence was mixed for subjects' use of a preferred movement speed in their responses to timed stimuli. On the one hand, 5-year-olds' movement speeds matched a stimulus' velocity only when it traveled at their previously preferred pace (Figure 5). When their average arm movement speeds were compared across the distance-covering and homing phases of the response, these too were equal, regardless of stimulus speed. Examining these results logically leads to a conclusion favoring a preferred speed concept (at least for young children). On the other hand, these same youngsters made slightly more corrections when responding to faster stimuli, and the duration of the correcting phase was longer than the distance-covering phase for faster stimuli. Taken together, these results suggest that even 5-year-olds' responses were not entirely stereotyped.

Table 3
Age and Stimulus Speed Differences in the Average Velocity of Corrections made during Timed Responses

	Stimulus Velocity (mph)		
Age	<2.0	2.1 – 4.0	>4.1
5	94.6[a](4)[b]	100.5(10)	141.1 (7)
7	52.9 (7)	101.4(12)	115.1 (4)
9	34.6 (7)	89.3(11)	204.6 (4)
Adult	36.0 (5)	109.1(14)	139.1(21)

[a] measures are in cm/s.
[b] number of trials.

The most obvious question then is what occurred during the homing phase that resulted in its longer duration? Since movement speed was the same, the answer may be in the number of corrections made or the magnitude of those corrections. In an earlier study, Salmoni (1983) suggested that young children's corrections may be of greater magnitude than older subjects', thereby increasing response time. Selected trials from this study have been examined to test the feasibility of this explanation (Table 3). Consistent with Salmoni's prediction, as stimulus velocity increased, the magnitude of the corrections also increased. While unsuccessful in appreciably increasing response accuracy, 5-year-olds apparently were able to attempt corrections, at least for faster stimuli. However, they lacked the ability to modulate these corrections appropriately.

Older children's responses were more accurate than the 5-year-olds. The 7- and 9-year-olds matched speeds moving slower than, or the same speed as, their baselines (Figure 5). At these speeds, the duration of the homing phase was greater than the distance-covering phase, despite no change in average movement velocity (although velocity differences for the 9-year-olds approached significance). Their accuracy did deteriorate in relation to faster stimuli, where results of movement time analyses suggested that they "resorted" to stereotypic movement speeds (Figure 5). Interpretation of the kinematic data suggests otherwise. While the overall accuracy of their responses was poor, the 7- to 9-year-olds did modify their actions: They increased their movement speed during the relatively short homing phase. Interestingly, there were no differences for either 7- or 9-year-olds in the number of corrections they made for the two stimulus speed groups. Perhaps these children were successful at more finely tuning their corrections at the expense of making enough corrections.

Movement time data (Figure 5) demonstrated that adults' accuracy was poor for most stimulus velocities. Kinematic data suggested that they were the most "adaptable" of the subjects. For example, adults made more corrections relative to slow stimuli than for fast light speeds. The distance-covering phase was shorter when responding to fast stimuli, demonstrating an ability to begin corrections sooner, when necessary. Movement speed was increased dramatically during the homing phase of these fast stimulus trials. Conversely, adults made their corrections at a slower speed (Table 3) over a longer duration, when stimuli traveled slowly. Therefore, while failing to be successful in increasing their accuracy, adults used strategies with the potential to optimize their precision. Their inability to be more accurate was related, in all likelihood, to the very high stimulus speeds they chose, rather than their lack of ability. Response time for adults was severely limited, averaging 350 ms for fast stimuli. At fast speeds, the duration of the DC and HOM phases was not different, suggesting that adults may have been approaching their maximum movement velocity. Further study is necessary to confirm this hypothesis.

Results of this investigation were consistent with earlier research in anticipatory timing. Subjects of all ages began their responses at the same pace, regardless of stimulus speed. It was as though subjects began each movement at the same moderate speed (Shea et al., 1982), while they attempted to determine, and then adjust to, the stimulus velocity given. During the homing phase, all but the 5-year-olds either slowed down or increased their movement speed as they attempted to match the stimulus.

Outcomes of the kinematic analyses also were consistent with findings of previous studies of rapid, aiming movements. Both Salmoni (1983) and Schellekens et al. (1984) found that young children attempted more corrections as task difficulty increased (they manipulated target size or movement amplitude). In the present study, 5-year-olds made more corrections in relation to faster stimulus velocities.

GENERAL DISCUSSION

Two experiments were performed as an initial attempt to explain age-related limitations in response accuracy for an anticipatory timing task. Results of Experiment I suggest that subjects used a preferred movement speed when response demands made it difficult for them to time their movements accurately. Initial analyses of the data from Experiment II confirmed this notion. The youngest subjects nearly always used a stereotypic speed, while older subjects resorted to using it only when stimuli traveled faster than their preselected pace.

Analyses of the kinematic data from Experiment II suggested that the concept of preferred movement speed, while appropriate, might be too simplistic to explain what actually occurred during a response. Even the youngest subjects did not move in an entirely stereotypic fashion across their range of stimulus velocities. Evidence from previous studies of reaching movements (Hay 1978, 1979) can give some clues about what children may have done as they responded. In Hay's experiments, 5- year-olds made ballistic movements that often ended with a sudden decelerative phase. Children's actions were accurate when they coincided with the objects' placement. By 7 years of age, children attempted to use visual information, even though it was unnecessary (and counterproductive) for guiding the reach. The result was an inaccurate outcome. Older children integrated their use of visual information with task demands, increasing their success (Hay, 1979).

A similar, age-related sequence was observed in the present experiment. For the most part, 5-year-olds performed ballistic movements, with little apparent regard for stimulus velocity. When arm speed matched light speed, they were accurate. Since a series of corrections was usually necessary, 5-year-olds typically responded either too soon or too late, Modifications observed during the homing phase for fast stimulus velocities probably represents the decelerative phase described by Hay (1979). Examination of average velocities suggested that smooth, gradual braking may have occurred relative to slow speeds; conversely, fast speeds resulted in a rapid braking action.

By 7-9 years of age, the children seemed to be attempting visually guided movements. In addition to making clear changes in movement velocity, especially during the homing phase, they were able to modulate the magnitude of their corrections. Their major shortcoming was an inability to complete a sufficient number of corrections, of appropriate magnitude, to optimize accuracy. It was as though these children could vary one component of the task (i.e., velocity), but could not manipulate two simultaneously (i.e., velocity, number of corrections). Seigler (1981) has suggested that young children may simplify problems that they cannot solve by relying "solely on the values of a single, most important dimension (p. 65)." Perhaps varying their movement velocity represents the dimension "selected" by these children. They may be able to change their movement velocity, but do not process feedback about its correctness quickly enough (Thomas, 1980) to make additional corrections under the strict time constraints of the task. This explanation is plausible, since these same subjects were able to respond appropriately to slower stimuli, with longer runway times.

Despite the poor outcome of their performances, adults changed their movement velocity and the number of corrections they made across the range of stimuli. Since adults responded accurately to slower stimulus speeds in Experiment I, the greatest difficulty in Experiment II seemed to be high speeds chosen. The amount of response time adults had was the most likely limiting factor for their accuracy (Shea, Krampitz, Tolson, Ashby, Howard, & Husak, 1981).

In conclusion, while at least 5-year-olds used a "preferred speed" in response to a range of stimulus speeds, this term has little explanatory power across age. Even when young children appeared to be making stereotyped responses, examination of kinematic characteristics suggested the occurrence of more complex behavior. Five-year-olds made predominately ballistic responses, regardless of stimulus velocity. A rapid, braking phase was added when stimuli traveled very fast. Older children began to modify the speed of their movements, but apparently had insufficient time to make the fine adjustments required. Adults' accuracy seemed limited primarily by the amount of available response time, since they changed their movement velocity and made multiple corrections when necessary to optimize their accuracy.

NOTE

1. Wiring diagrams for these modifications were made available by Dr. Charles Shea, Texas A & M University

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