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The Graduate School

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CHILDREN'S AGE-RELATED PERFORMANCE IN STRIKING MOVING TARGETS

A Thesis in

Kinesiology

by

Alek Rothenberg-Cunningham

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The thesis of Alek Rothenberg-Cunningham was reviewed and approved* by the following:

Karl M. Newell
Professor of Kinesiology and Professor of Biobehavioral Health
Thesis Advisor
Head of Department

Robert L. Sainburg
Professor of Kinesiology and Professor of Neurology

Byron C. Jones
Professor of Biobehavioral Health and Pharmacology

*Signatures are on file in the Graduate School.

ABSTRACT

Previous studies of coincidence-anticipation timing have indicated that age-related improvements in accuracy appear to asymptote between late adolescence and early adulthood. Moreover, performance differences between males and females have been reported, although with less consistency. Contextual factors and target properties have been proposed as playing a role for the observed age and sex effects although approaches to elucidate the underlying mechanisms, including perceptual-motor systems, have been more concentrated to adult populations.

In this experiment we investigated the effect of target velocity and gravity influences on children's age-related interceptive performance. There were 4 levels of gravity and 4 levels of velocity applied to the target trajectory. Interception accuracy, response latency, movement time and performance scores for interceptions were measured in 4 age groups of participants 7-8, 11-12, 15-16 and 19-20 years of age (*n* = 10). The targets to be intercepted were presented on a digital graphics tablet using a custom program that simulated aspects of baseball. Performance scores, given for each trial that resulted in a positive hit (as opposed to a foul), represented the distance the target/ball travelled after being struck. It was hypothesized that younger children would exhibit longer response latencies and movement times and that females would attain lower performance scores compared to males as contextual factors, rather than biological factors, are more likely to augment the males' responses as the current task demands are more similar to activities engaged by males at younger ages.

The results showed that younger children performed with the least amount of accuracy and were affected more by higher target velocity. Females age 7-8 years initially exhibited less accuracy in interception but had significantly greater accuracy compared to males age 11-12 years. Despite reaching a mature level of accuracy at an earlier age, females' distance scores remained lower compared to males across all ages. The persistence of speed-coupling effects, correlating effector response earlier or later for faster or slower moving targets, respectively, is taken as evidence that target velocity is a critical factor in the perceptual-motor system. The large difference in performance between younger and older children, adolescents and adults may reflect a less developed perceptual system and/or a more rudimentary method for predicting target locations.

TABLE OF CONTENTS

List of Tables

List of Figures

Introduction

Manual target interception is a coincidence-anticipation timing skill that requires the ability to initiate and complete the movement of an effector such that it coincides with the arrival of a moving object at some set interception position (Bard, Fleury & Gagnon, 1990), or within a range of positions, as long as the effector arrives coincident with or before, though not after, the arrival of the target (Bairstow, 1987). Interception is evident in everyday life from simple tasks like grabbing a pencil on a desk to more complex activities such as catching or striking a moving ball, or catching a pencil as it rolls off of a desk. Development of interception, as a skill, exploits an ability to estimate the movement parameters of an object in order that some prediction can be made about the future object locations and to some degree, estimate the probability of target avoidance or collision. Improvement in the ability to intercept moving objects has been shown to correlate with children's age (Bard et al., 1990) although the pattern of developmental changes in the perceptual-motor processes that enrich performance remains ambiguous.

Investigations of coincidence-anticipation timing have consistently found qualitative and quantitative differences for intercepting moving targets between young children, adolescents and adults (Bard et al., 1990; Dunham, 1977; Haywood, 1980; Haywood, Greenwold & Lewis, 1981; Williams, Jasiewicz, & Simmons, 2001). For instance, children 5-7 years old have been shown to produce less smooth velocity profiles and deviate from a constant bearing angle in comparison to older participants intercepting objects at various velocities (Chohan, Verheul, Van Kampen, Wind & Savelsbergh, 2008). Pavlis (1972) showed that the accuracy of younger children was significantly lower when manually intercepting targets of varying duration.

A diversity of experimental designs makes it difficult to compare the findings across studies (Stadulis, 1985; Bard et al., 1990). Regardless, task specific constraints have produced performance results that, while perhaps limited to a specific context, illustrate that younger children consistently perform differently compared to older participants. Stadulis (1985) found that younger children had poorer temporal accuracy compared to older participants, however, temporal errors were inconsistent across designs that required either a key release or a button-press at the moment of target arrival at the designated interception position. Dorfman (1977) using a joystick, and later Ball and Glencross (1985) using a manual slide, had participants intercept a falling target on a monitor. Younger children had greater temporal error in both experiments, and Dorfman (1977) also showed that younger children had a lower differential rate of learning in that trial-to-trial improvement in performance was slower compared to older participants.

Target speed has consistently been shown to affect interceptive performance across and within age group. The velocity of the target has been shown to influence effector velocity although the positive correlation between target and effector velocity is higher among younger children (Bard et al., 1990; Brenner et al., 1998; Fleury et al., 1998). Haywood, Greenwald and Lewis (as cited in Benguigui, Broderick, Baures & Amorim, 2008, p. 390) provide a cogent explanation for the observed velocity effects in interceptive tasks. The assimilation hypothesis posits that younger children use a spatial reference position that serves as a marker at which, upon target arrival, a motor response is initiated. Using the speed of the previous target to augment the current motor response, the rate of effector translation is adjusted slightly about an averaged target-speed. The outcome of this strategy results in predictable temporal error where responses are early for slow-moving targets and late for faster targets.

An additional behavior found to relate to target velocity is speed-coupling, an effect that appears to persist across ages and describes the positive correlation between target and effector velocities where changes in target velocity are correlated with similar effector velocity adjustments (Brenner et al., 1998; Brouwer et al., 2000; Dubrowski, Lam, & Carnahan, 2000; de Lussanet, Smeets, & Brenner, 2001). Speed-coupling is also indicated as influencing response initiation with movements beginning earlier for faster moving targets and later for slower targets. Several factors relating to target movement and velocity have been considered in identifying the features of a moving object or target that prompt interceptive behavior. The perception of target variables such as the temporally based, *tau* hypothesis (Lee, 1976) and other variations of time-to-contact (Zago et al., 2009) have been proposed for the role of information used in interceptive responses.

Past research has indicated that information about a target's trajectory is determined early in the trajectory pathway (Van Donkelaar, Lee & Gelman, 1992) and is largely independent of target velocity. The influence of gravity has been investigated although the contexts for target-gravity performance have largely measured temporal accuracy for tasks where the target falls along the ordinate only (Baures et al., 2007; Zago et al., 2009). Given that trajectory is determined early, it is expected that, in the current experiment, differences in response times will not be because of the level of gravity. However, increased gravity, imposing greater curvilinearity on the target, is expected to result in a decrease in movement times as participants would move more quickly in order to intercept the target earlier in the trial, before the curvilinearity increases with the acceleration of gravity. Because the performance score (see methods) is a product of effector velocity and angle of incidence at contact, participants will want to avoid having to pursue the target and intercept it head-on.

The role of visual information is perhaps the most examined facet of perceptual-motor processes in target tracking and interception although securing empirical evidence as to what target variables (e.g. time-to-contact, viewing time) might be most critical to interception has been a challenge. Intrinsic compliance has been indicated as influencing the extra-retinal perceptual systems (vestibular signals and proprioception of head and neck muscles), showing that various systems can accommodate and fully compensate when the visual information is restricted (Bongers & Michaels, 2008). Variables such as absolute and relative rate of expansion have also been examined although conclusions are mixed as to which optical variables are optimized during interception tasks (Calijouw, Van der Kamp, & Savelsbergh, 2004; Zago et al., 2009).

The limited number of observed sex differences in interceptive tasks can, in part, be attributed to a paucity of experimental data (Dorfman, 1977). Despite the limited basis of comparison, the existing data do indicate differences in performance between sex. Dorfman (1977) reported that sex differences, which indicate males as initially performing with more accuracy, are more apparent at younger ages and that these differences diminish with age. Dunham (1977) attributed sex differences to contextual as opposed to biological factors. Sex differences in performance in the current examination will be considered in relation to age/experience. It is anticipated that males will initially perform with higher level of accuracy and will obtain higher performance scores compared to females. If contextual factors and experience are primary to the differences between sexes, the differences should diminish with age as performance has been indicated as reaching an asymptote during mid to late adolescence.

In the current experiment, participants across 4 age-groups (7-8, 11-12, 15-16 & 19-20 years) are examined while performing an interceptive task in which target velocity and trajectory are varied. Whereas several past investigations have measured temporal error, the current design allows participants to self-select the intercept position. Obtaining a measure of temporal error is therefore not possible, although spatial accuracy can be examined via a more rudimentary method of quantifying the number of interceptions. Improvement in performance will manifest as a reduction in the number of misses with developmental age. Near hits, or touches (similar to a foul-ball) are examined as it is expected that as accuracy improves there will be an intermediate stage where a shift from fewer misses to more touches and then more hits. In addition to the number of hits, the outcome of interceptions is measured as these scores, representing the distance the target travels after interception, reflect the effector velocity at the time of impact. It is hypothesized that improvements in accuracy with age will be shown to take place through a transition where the decrease in the number of misses from the 7-8 year olds is distributed largely as touches among the 11-12 year old participants, and as in increase in the number of hits that will be shown reach an asymptote at age 15-16 years.

Methods

Participants: A total of 40 participants in age groups (*n* = 10) of 7-8 (7 male, 3 female), 11-12 (6 male, 4 female), 15-16 (4 male, 6 female) and 19-20 (5 male, 5 female) years of age were recruited. Both left- and right-hand dominant (as determined by the hand with which writing is performed) participants were included. All participants had normal or corrected-to–normal vision and had no history of seizure disorder. All participants were naïve to the purpose of the research. Each participant completed a single session lasting no more than 1 hr and received monetary compensation for their time. All participants were recruited through approved newspaper and electronic media. The participants provided signed assent and consent as approved by the University Institutional Review Board

Apparatus: The interactive device used was a WACOM Cintiq 21UX digital tablet with the dimensions 561mm x 421mm x 61.3mm that has an active surface area of 432mm x 324mm. The sample rate was 140Hz. A hand-held, cordless stylus with a weight of 18g was used with the digital graphics tablet. The screen-face was upright at an angle of 60^{o} (from horizontal).

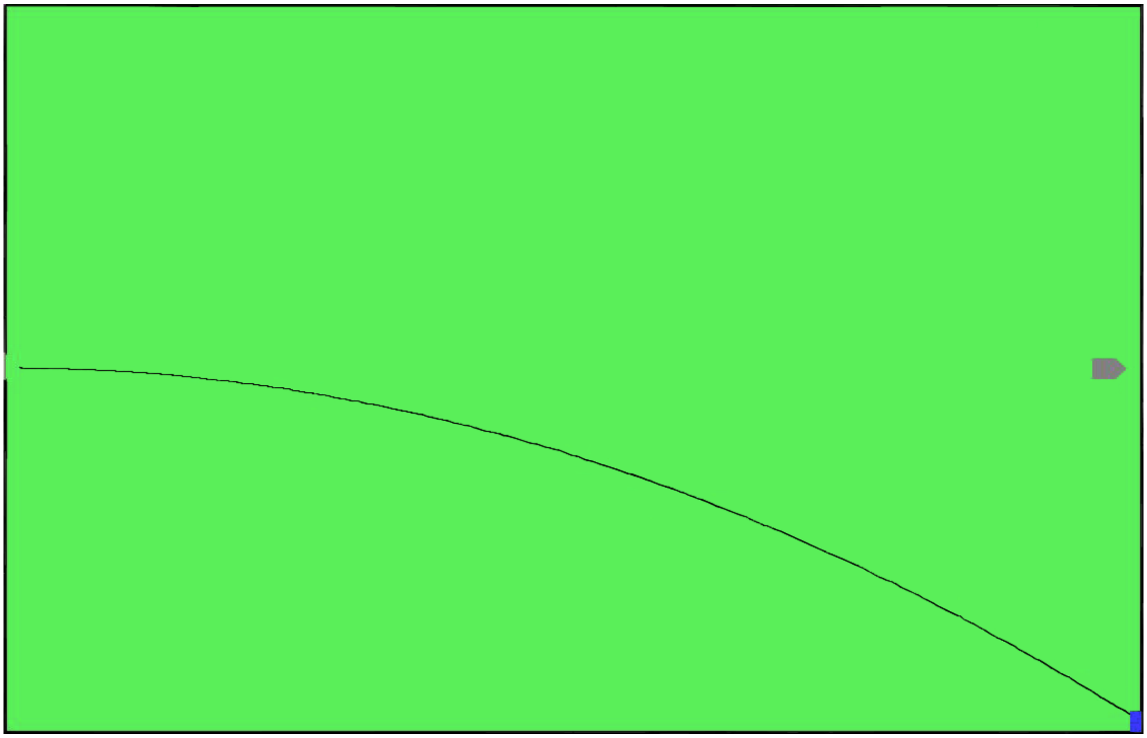

Figure 1. The virtual environment with target trajectory trace for gravity x 1.5 at velocity 30m/s.

Program: A custom computer program was created to simulate components of American Baseball; the game-like program was selected as a means to maintain arousal and interest of the participants. The starting location was a polygon configured to simulate the appearance of home-plate that was positioned at horizontal minimum and maximum pixel positions 976 and 1006 (respectively) and at vertical minimum and maximum pixel positions of 349 and 369 (respectively). Figure 1 displays the virtual environment with a trace of the target/ball trajectory for gravity x 1.5 (-14.7 m/s/s) and target velocity at 30 m/s. The width of the front of the home plate measured 30 pixels wide while the parallel sides measured 20 pixels in length. The angles of the rear of the home plate each measured 18 pixels in length. The target measured 25 x 25 pixels and was assigned a mass of .15 kg with a coefficient of restitution = 0.46. The stylus controlled cursor measured 13 x 13 pixels and had an assigned mass of .95 kg. The onset of movement was determined to be at the instant the stylus controlled cursor exceeded a velocity of 2cm/s. The setting for handedness automatically inverted the field in order that the measurements would remain consistent between left- and right-hand dominant participants.

Table 1 displays the gravity and velocity conditions used for the task. Targets travelled at the velocities of 30, 40, 50 and 60 m/s and were influenced by gravity (-9.8 m.s.s.) multiplied by weightings of .05, .5, 1 and 1.5. The assignment of target velocity and gravity conditions was randomized across participants. Each participant completed 4 trial blocks. Each trial block was randomly assigned to one of 4 gravity conditions. Within each gravity condition each of the 4 levels of velocity were randomly presented in blocks of 12 trials.

Target Velocity (m/s)	**Gravity (-m.s.s)**
30	0.05
40	4.9
50	9.8
60	14.7

Table1: Target velocity and gravity conditions

Task: Participants performed the task individually and independent of other participants. Participants were seated in an adjustable chair at a height that was "most comfortable for their arm/hand to move across the graphics tablet surface". A piece of white tape 3/8-in in width was placed on the table surface in front of and below the graphics tablet screen. This was the reference mark for which participants would be centered, approximately along a sagittal midline of the body, prior to each block or as needed between trials.

The task was verbally described to each participant: “Start by placing the stylus tip on the home-plate and remain there for 1-2 s. A target will appear and it will be moving across and down the screen sometimes very fast, other times more slowly. The goal is to hit the target as hard as possible so the target/ball will go as far as possible. You can choose when to start moving and where you want the hit the target so it goes as far as possible. After you hit a target, if it goes in the forward direction and is not like a foul-ball, you will get a score which shows how far the target went (m). When you are ready to continue, close the score-box by placing touching the tip of the stylus on the “close” button in and place the stylus in the home plate to start the next trial.” After contact, the target would travel in the direction of the impact and would continue to travel (unseen if beyond the edge of the screen) until the gravity constraint would cause the target to strike the surface.

Results

Table 2 shows the mean total for all interceptions, the hits that resulted in a positive outcome score, touches, and misses for each age group. Table 3 shows the percentage of contacts, positive hits, touches and misses with respect to sex and age group.

Age (years)	All Interceptions	Positive Scoring Hits	Touches (fouls)	Misses
7-8	801	771	30	159
11-12	846	832	14	114
15-16	899	887	12	61
19-20	912	897	15	48

Table2. Number of interceptions for each age group for: all interceptions, touches (foul-balls) and misses

.Sex	Age (years)	Total # Trials	% Contacted	% Hit	% Touched	% Missed
Male	7-8	672	84.82	81.55	3.27	15.18
	11-12	576	85.24	84.20	1.04	14.76
	15-16	384	94.79	92.19	2.60	5.21
	19-20	480	94.79	93.33	1.45	5.21
Female	7-8	288	80.21	77.43	2.78	19.79
	11-12	384	92.45	90.36	2.08	7.56
	15-16	576	92.88	92.53	.35	7.12
	19-20	480	95.21	93.54	1.67	4.79

Table 3. Percentage of total trials resulting in contact, positive scoring hit, touches (foul-balls) and misses for sex and age-group.

Interceptions. A Mantel-Haenszel test was used to identify linear correlations between the independent variables and the outcomes. A significant effect of age was identified, $\chi^2(1, N = 40) = 93.62$, $p < .001$. A Pearson correlation coefficient, $r = -0.156$ (two-tailed) < .05, revealed that as age increased the number of misses decreased. A significant effect of sex was also indicated, $\chi^2(1, N = 40) = 6.84$, $p < .001$. A Pearson correlation coefficient, $r = -0.042$, p (two-tailed) < .05, showed that males are more likely to miss a target compared to females. Velocity was shown to be significant, $\chi^2(1, N = 40) = 9.47$, $p < .01$, with a Pearson correlation coefficient, $r = 0.048$ (two-tailed) < .05, showing that more misses occur as target velocity increases. Gravity was also a significant factor, $\chi^2(1, N = 40) = 6.24$, $p < .05$. A Pearson correlation coefficient, $r = 0.040$, p (two-tailed) < .05, indicated that increased gravity resulted in fewer interceptions.

Further examination indicated that the 15-16 and 19-20 year olds had significantly more hits than the 7-8 and 11-12 year olds. The 11-12 year old group also had significantly more hits than the 7-8 year olds. The 7-8 year old group had significantly more touches, compared to the 11-12 and 15-16 year old ages. Post-hoc analysis also indicated a significant difference in the number of misses with the 7-8 year olds having the largest number of misses followed by the 11-12, 15-16, and 19-20 year olds, respectively. The 15-16 and 19-20 year olds did not differ in the number of missed targets.

Velocity was significant for the number of touches and misses with more touches taking place at the 30 m/s condition compared to the 50 m/s condition. Significantly more misses were obtained for the 50 and 60 m/s conditions compared to the 30 and 40 m/s conditions.

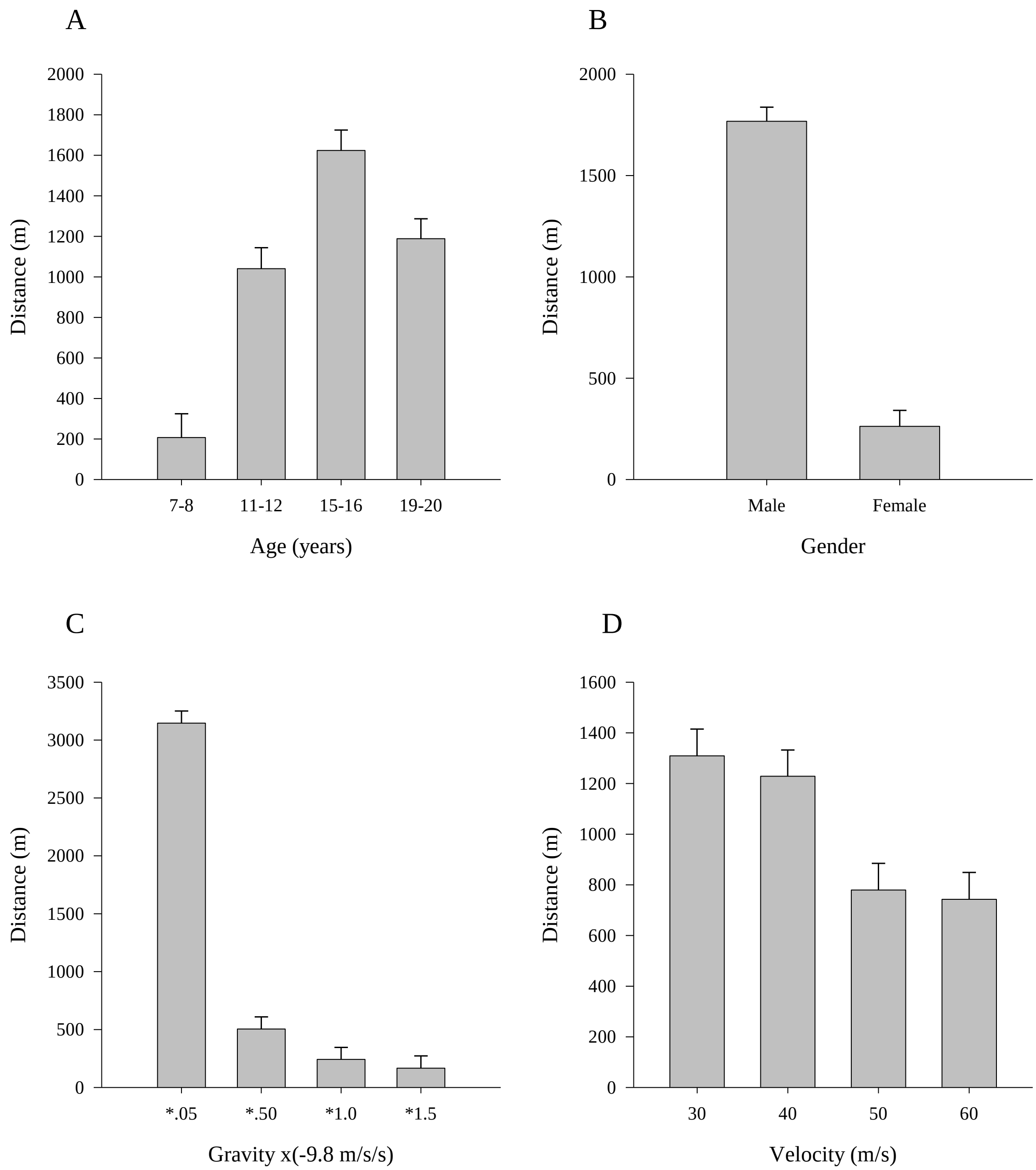

Figure 2. Distance scores (m) as a function of A) age, B) sex, C) gravity and D) velocity conditions.

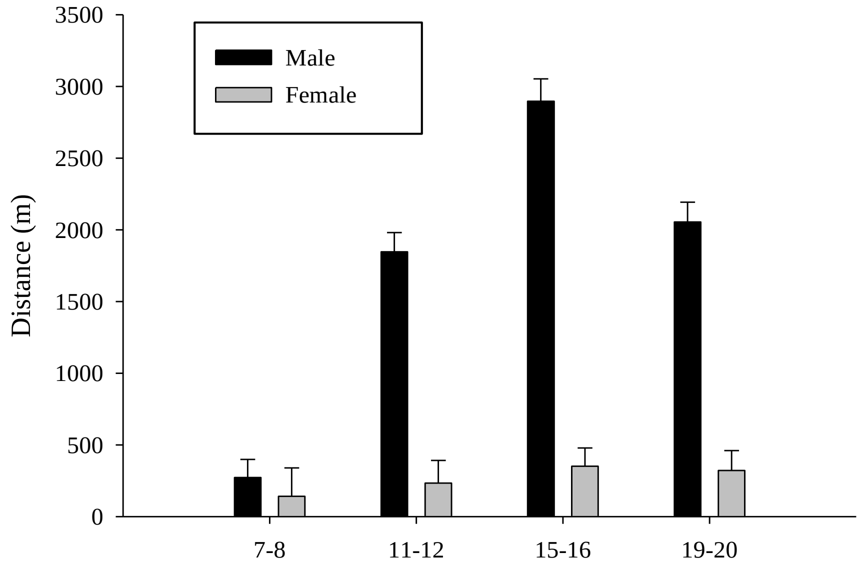

Figure 3. Distance as a function of the age x sex interaction

Distance: Figure 2 shows the mean distance hit as a function of age, sex, gravity and velocity. Figure 3 displays distance as a function of age and sex. Statistical analysis was performed on only those trials in which an interception resulted in a positive distance score (misses and touches excluded).

The results of the univariate ANOVA indicated significant main effects for age, $F(3, 3254) = 28.596$, $p < .05$, $\omega = .12$, sex, $F(1, 3254) = 204.956$, $p < .05$, $\omega = .20$, gravity, $F(3, 3254) = 185.784$, $p < .05$, $\omega = .33$, and velocity $F(3, 3254) = 7.859$, $p < .05$, $\omega = .06$. Significant interactions were found for age x sex, $F(3, 3254) = 20.540$, $p < .05$, $\omega = .10$, age x gravity, $F(9, 3254) = 19.308$, $p < .05$, $\omega = .18$, sex x gravity, $F(3, 3254) = 125.088$, $p < .05$, $\omega = .27$, sex x velocity, $F(3, 3254) = 6.460$, $p < .05$, $\omega = .06$, gravity x velocity, $F(9, 3254) = 6.439$, $p < .05$, $\omega = .09$, age x sex x gravity, $F(9, 3254) = 15.785$, $p < .05$, $\omega = .16$, and sex x gravity x velocity, $F(9, 3254) = 5.139$, $p < .05$, $\omega = .08$.

Post-hoc analysis indicated that the lowest distance scores were achieved by the 7-8 year olds with significantly longer distance scores for the 19-20, 11-12 and 15-16 year olds, respectively. There were no significant differences between any of the ages older than 7-8 years. At gravity x .05 distances were significantly longer compared to the gravity x .5, gravity x 1 and gravity x 1.5 conditions (in that order). There were no significant differences between any of the other gravity conditions. The distance scores for the 30 m/s and 40 m/s velocity conditions were significantly larger compared to the 50 and 60 m/s velocity conditions. There was not a significant difference between the 50 and 60 m/s velocity conditions.

Correlation: A Pearson correlation confirmed a significant relationship between gravity and distance, $r = -.284$, (one-tailed) $p < .05$, that, while low, supports the expectation that lower distance scores are obtained at increasing gravity as the target is returned to the ground surface at a faster rate of acceleration. Velocity was also shown to significantly relate to distance, $r = -.065$, (one-tailed) $< .05$, which was anticipated to result, in part, as a function of reduced time to increase effector velocity prior to target contact when target velocity is higher.

Movement Analysis: Figures 4a and 4b display the average response latency for the gravity by velocity interaction across each age group and sex.

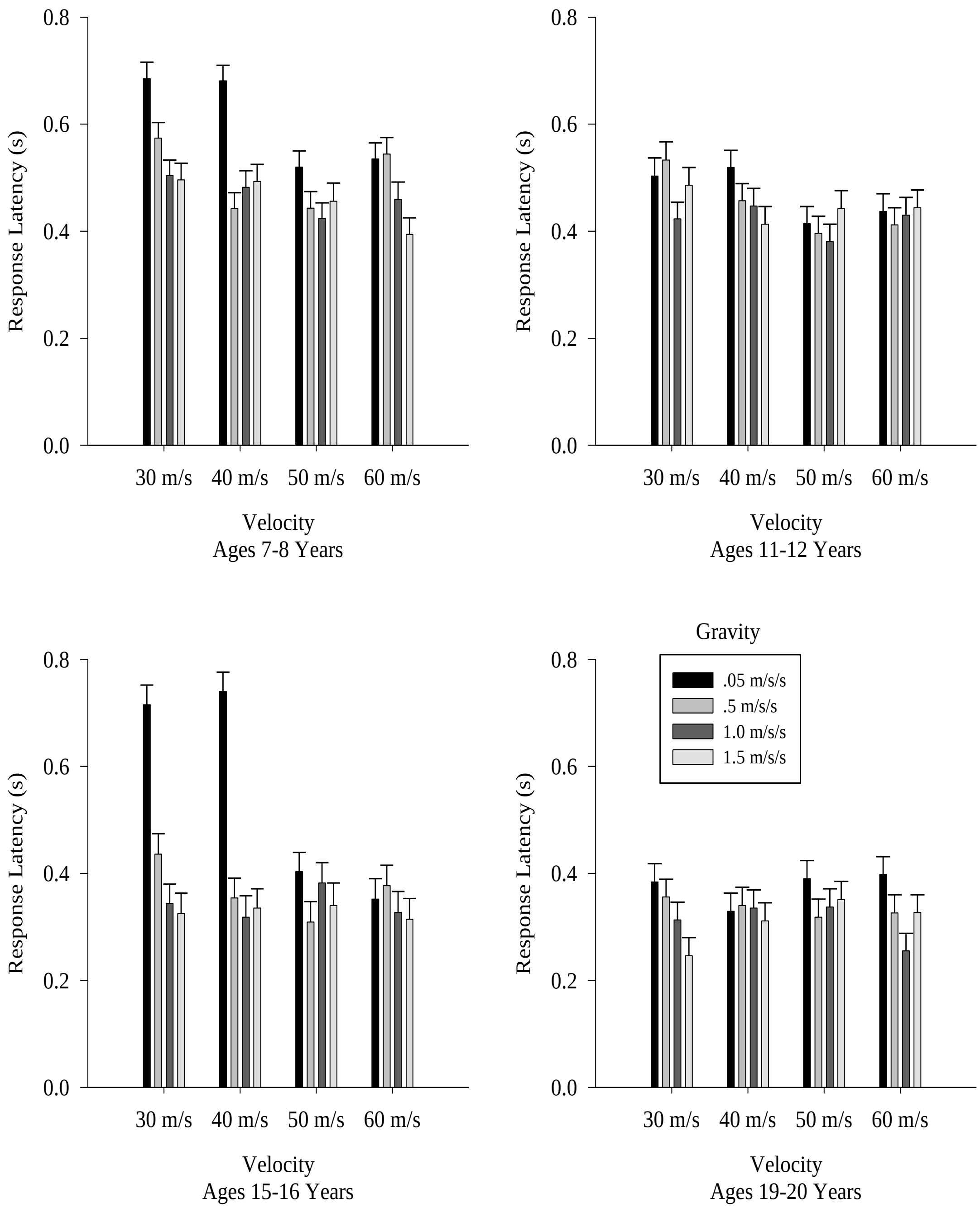

Figure 4a. Gravity by velocity (virtual) interaction for response latency for males (error bars 95% confidence interval)

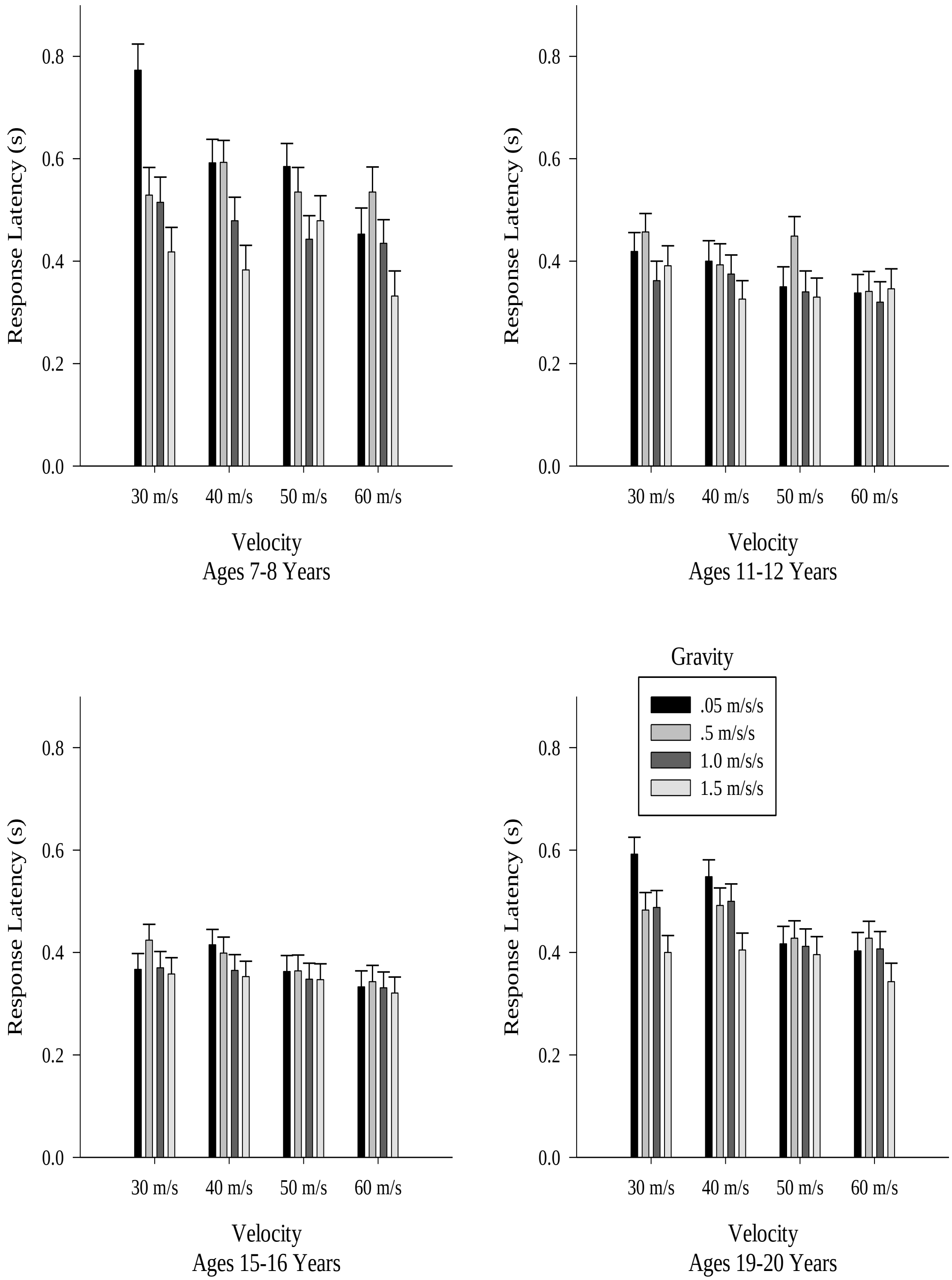

Figure 4b. Gravity by velocity (virtual) interaction for response latency for females (error bars 95% confidence interval)

Response latency. A univariate ANOVA was conducted on the response latency scores for age, sex, gravity and velocity main effects and interactions. Significant main effects were indicated for age, $F(3, 3254) = 72.138$, $p < .05$, $\omega = .04$, gravity, $F(3, 3254) = 49.446$, $p < .05$, $\omega = .19$, and velocity, $F(3, 3254) = 26.348$, $p < .05$, $\omega = .13$. Significant interactions were shown for age x sex, $F(3, 3254) = 45.295$, $p < .05$, $\omega = .18$, age x gravity, $F(9, 3254) = 4.629$, $p < .05$, $\omega = .08$, sex x gravity, $F(3, 3254) = 7.475$, $p < .05$, $\omega = .07$, gravity x velocity, $F(9, 3254) = 5.457$, $p < .05$, $\omega = .10$, age x sex x gravity, $F(9, 3254) = 4.365$, $p < .05$, $\omega = .08$, age x sex x velocity, $F(9, 3254) = 2.965$, $p < .05$, $\omega = .06$, age x gravity x velocity, $F(27, 3254) = 1.685$, $p < .05$, $\omega = .06$ and age x sex x gravity x velocity, $F(27, 3254) = 1.969$, $p < .05$, $\omega = .08$.

Post-hoc analysis for response latency indicated that 7-8 year olds had significantly longer response latency times compared to 11-12, 15-16 and 19-20 year olds. 11-12 year olds had significantly longer response latencies compared to 15-16 and 19-20 year olds. Response latencies were significantly longer for the gravity x .05 compared to the .5, 1.0 and 1.5 gravity conditions. Significantly longer response latencies were also observed for the gravity at .5 compared to the 1.0 and 1.5 conditions. Response latencies were also indicated as being longer at the 30 and 40 m/s conditions compared to the 50 and 60 m/s conditions.

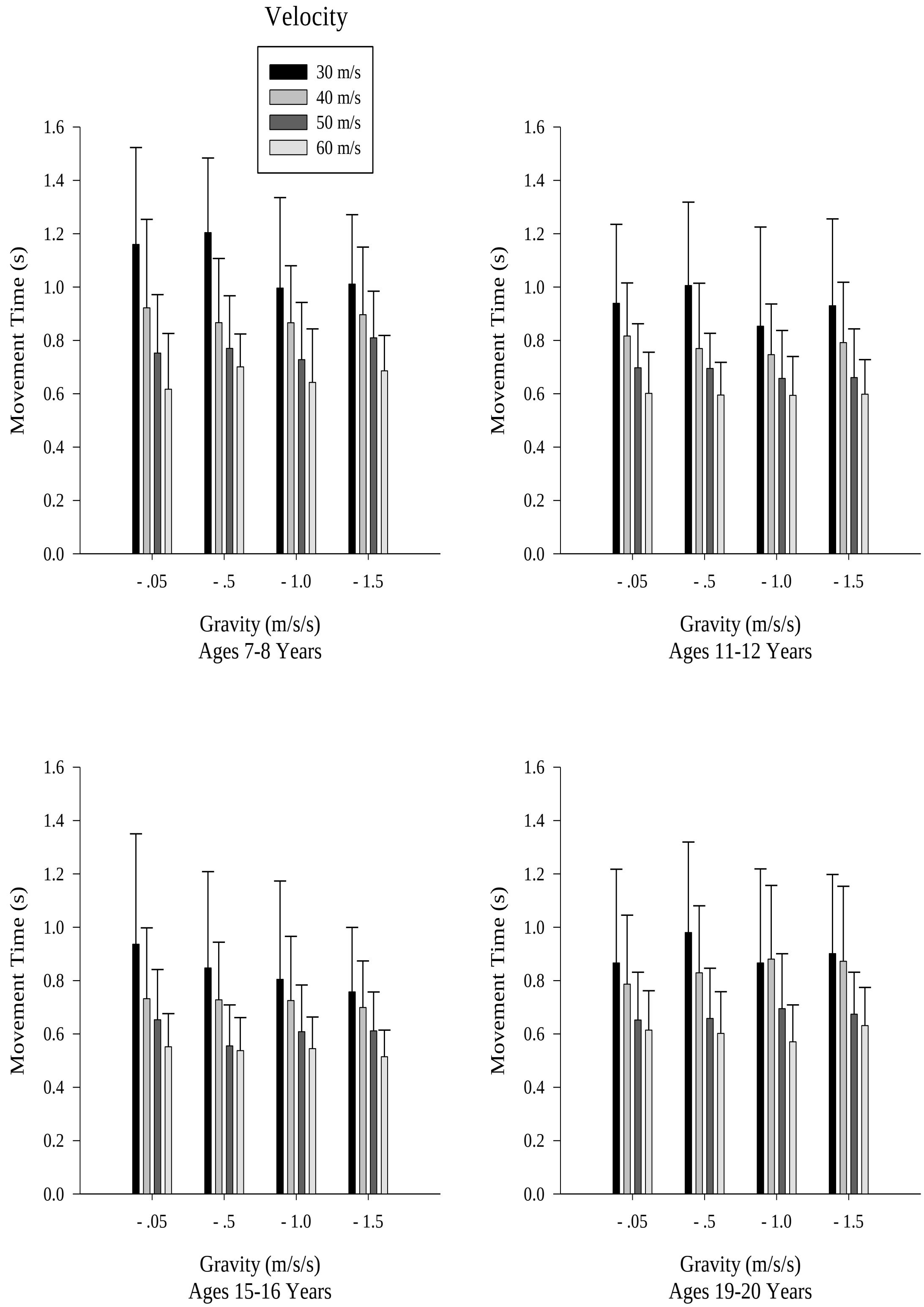

Figure 5. Movement time as a function of age, gravity & velocity (error bars: 95% confidence interval).

Movement time. An ANOVA was used to examine the main effects of, and interactions between age, sex, gravity and velocity conditions for movement time. Only those trials resulting in an interception (hit or touch/foul) were examined. Significant main effects were found for age, $F(3, 3250) = 61.720$, $p < .05$, $\omega = .18$, sex, $F(1, 3250) = 209.687$, $p < .05$, $\omega = .20$, gravity, $F(3, 3250) = 4.189$, $p < .05$, $\omega = .04$, and velocity, $F(3, 3250) = 362.170$, $p < .05$ $\omega = .44$. Significant interactions were indicated for age and sex, $F(3, 3250) = 25.806$, $p < .05$, $\omega = .12$, age and gravity, $F(9, 3250) = 3.331$, $p < .05$, $\omega = .06$, age and velocity, $F(9, 3250) = 2.616$, $p < .05$, $\omega = .06$, sex and gravity, $F(3, 3250) = 2.739$, $p < .05$, $\omega = .03$, sex and velocity, $F(3, 3250) = 13.984$, $p < .05$, $\omega = .09$, gravity and velocity, $F(9, 3250) = 4.667$, $p < .05$, $\omega = .08$, age, sex and gravity, $F(9, 3250) = 2.170$, $p < .05$, $\omega = .04$, age, sex and velocity, $F(9, 3250) = 6.110$, $p < .05$, $\omega = .09$ and age, sex, gravity and velocity, $F(27, 3250) = 1.703$, $p < .05$ $\omega = .06$.

Post-hoc analysis for movement time by age showed the 7-8 year olds as having significantly longer movement times compared to all other age group. The 11-12 year old group had significantly longer movement times compared to the 15-16 year old group, who were shown to have the shortest movement time. At the gravity x 1.0 condition, movement times were significantly lower when compared to the gravity x .05 and gravity x .5 conditions. The longest movement time was indicated for the gravity x .05 condition. as well as at the 30 m/s velocity condition. Movement times reduced by significant amounts as velocity increased from 40 to 50 m/ and from 50 to 60 m/s, a result taken to indicate that reduced task time was the primary factor for the significant reductions observed. Males had shorter movement times, a finding that is congruent with the finding that males had markedly higher performance scores compared to females. Although significant, the correlation between movement time and gravity, r = -0.030, p (one-tailed), < .05 was low, leading to the conclusion that in the current context, gravity was less influential on response behavior compared to velocity.

Discussion:

Consistent with past studies, interception accuracy improved with developmental age and performance was shown to reach an asymptote between mid-adolescent and young adulthood ages (Bard et al., 1990; Dorfman, 1977; Dunham, 1977; Haywood, 1980; Haywood et al., 1981; Williams et al., 2001). This developmental progression has been found for other interceptive actions including both single-handed and two-handed catching, kicking, and striking with a bat (Payne & Isaacs, 2002). The improvement in accuracy and performance scores, however, was not consistent across females and males.

The effects of target trajectory properties in the current experiment are consistent with those previously interpreted as a reflection of speed-coupling (Brenner et al., 1998; Brouwer et al., 2000; Dubrowski et al., 2000; de Lussanet et al., 2001). Children ages 7-8 years were more affected by target velocity, providing additional support to the hypothesis that younger children exhibit speed-coupling behavior to a greater extent (Bard et al., 1990; Brenner et al., 1998; Fleury et al., 1998). The persistence of velocity effects across age groups is taken as evidence that interceptive responses are likely influenced by a variable associated with target speed although association with time-to-contact, a value that decreases over time, is difficult in a paradigm in which an interception position is not defined. Consequently, the self-selection of an interception position makes a null case for an assimilation hypothesis which only further begs the question as to what may be underlying the behavior that produces dramatic differences in accuracy between younger and older children, perhaps over a duration as little as 1-2 years?

Debate exists concerning the processing of target trajectory information and whether an intrinsic conception of target properties is transformed into meaningful information that allows for a calculation of a time to contact Zago et al. (2004, 2008 & 2009) or if response behavior is guided by on-line information (Baures, Benguigui, Amorim & Siegler, 2007). The pitfalls for time-to-contact models is that for target durations of less than approximately 200 ms alternative explanations can account for the motor action that takes place during a period of time that does not theoretically allow for a sensory-feedback process to fully realize and anticipate future conditions for a response (Baures et al., 2007; Brenner et al., 1998). Zago et al. (2008) explain that continuous on-line control is limited with respect to the same time period prior to contact in that an ongoing control mechanism would likely not be able to perceive and respond to movement error during the final 200 ms. Examining the current findings with respect to predictive and prospective control mechanisms, some promise of opportunity to further understand the perceptual-motor process appears although for the time being, there will continue to exist limitations in what can be offered to placate the theories in terms of the control mechanism(s) operating during the final moment prior to contact.

It has been suggested that there is a reliance on prior knowledge (experience) and not only visual cues for the use of internal models (Zago et al., 2009). An internalization of target features runs counter to Baures et al. (2007) who instead support continuous control paradigms. In such a paradigm, however, the inherent neuromechanical delays would prevent such on-line control (Zago et al., 2008). On-line control could be reasoned for the fact that females were observed to excel quickly in accuracy improvements while males optimize internal models to obtain accuracy with speed at a later age, but such an assertion then might unintentionally instigate a schism with internal models being applied to speed-based performance and on-line control for emphasis on accuracy. With the additional consideration of confounds that arise with respect to the flexibility of the perceptual input mechanisms (see Bongers et al., 2008), speculating other non-biological factors should be considered.

Developing a cogent theory for the differences in interceptive performance between sex remains a challenge that is further complicated with variations in past findings (Bard et al., 1990; Dorfman, 1977, Dunham, 1977). In the present experiment the significant difference in performance between males and females provides grounds for speculation although identifying any firm factors that correlate with the sex-related differences is difficult as variations in past findings (Bard et al., 1990; Dunham, 1977) continue to remain unresolved, largely due to lack of data (Dorfman, 1977). Females' accuracy reached an asymptote at age 11-12 years but performance scores increased only later at ages 15-16 and 19-20 years. The accuracy of males was show to asymptote not until ages 15-16 years, however, while females ages 15-16 and 19-20 years did show some improvement in distance scores, males, by comparison, achieved markedly higher distance scores at all ages (see Figure 3). Until the identification of any perceptual mechanism and source of meaningful information can be linked, establishing biological factors for the differences between sex during interceptive performance is going to be tricky.

Thomas and French (1985) have suggested that the single most important factor for performance differences between sexes is that males are introduced to competitive gaming earlier and generally engage in such activities longer than females. Dunham

(1977) reported males as performing coincident timing tasks more than females and suggested that sex differences were possibly due to contextual rather than biological factors. Variables such as sex role identity and perceptions about females (i.e., being more fragile) have been suggested in trying to better account for differences often observed between sex (Payne et al., 2002; Thomas et al, 1985), however, the inherent conundrum lies in burden of obtaining empirical support for social constructs. This illustrates again how a more comprehensive understanding of the perceptual-motor mechanisms involved in information processing and planning might allow for more substantial correlations to be made.

Ultimately, velocity appears to be the most persistently identified variable influencing performance in experiments of interception. The interpretations of responses to changes in target properties in the current experiment prompts several questions about the existing data and the observed performance differences. The freedom to self-select an interception position allows participants to modify time to contact as the accommodation between response initiation, movement time and effector velocity can be used to exploit either or a combination of speed and/or accuracy. With biological factors appearing unlikely to directly influence performance differences between sex, thus far, there may yet be processes that explain performance improvements with age.

Examining the temporal component of interception, perhaps it can be indicated that there is a possibility for the perceived time variables to be used in order to determine what possibilities might be realized in terms of achieving a goal given the current state of conditions. That is, a notion of “what can be achieved in *X*-amount of time” provides support for the improvement with age, perhaps as a function of augmenting existing knowledge for increasing an internal compendium of movement plans, as may be the case for internal models. That the effects of velocity diminished or reached an asymptote with age leads to the suggestion that a self-selected interception position allowed older participants, who presumably have a better understanding of the spatiotemporal relationship, to initiate more of an incisive movement plan. This is supported by the findings that the performance of younger children is lower compared to the performance of older participants across experimental designs. Explaining the differences in interception between the sexes, however, is limited to the contextual, social and cultural factors mentioned earlier.

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