Controlling Reaching Movements with Unpredictable Object Motion

Moritz M. Daum
Institute of Psychology, University of Zurich, Switzerland
mmdaum@access.unizh.ch

Horst Krist
Institute of Psychology, University of Zurich, Switzerland
hkrist@genpsy.unizh.ch

Susanne Huber[1]
Institute of Psychology, University of Zurich, Switzerland
susanne.huber@tuebingen.mpg.de

Abstract

In the experiment we investigated the reaching behaviour of 10-year-old children and adults for virtual objects moving either on a predictable (linear) path or an unpredictable path (with random direction changes). 24 adults and 24 10-year-olds observed a spherical object which varied in the predictability of motion (linear vs. nonlinear) and the speed of object motion (17 cm/s vs. 24 cm/s). In an action condition the participants had to reach for the objects via a force-feedback device. We compared reaching movements for the linearly moving object with reaching movements for the nonlinearly moving object (but only those trials were evaluated where the normally unpredictable object moved linear). We analysed initial movement direction and maximum speed of the first submovement. In a judgement condition participants indicated the initial movement direction on a rating scale. Children and adults produced higher initial movement speeds and the initial movement direction was geared further towards the current position of the object for unpredictably moving objects. Our results show that predictable and unpredictable behavior is processed differently.

1. Introduction

We investigated the visuomotor control of children and adults reaching for an object that was displayed on a computer monitor and moved either predictably or unpredictably. In various interception tasks, reaching for linearly moving objects has been studied by researchers interested in human motor control (see Schmidt, 1988) and the development of perceptual-motor skills (see Keogh & Sugden, 1985; Dorfman, 1977; Williams, 1973).

Cognitive aspects of interception skills have rarely been investigated in detail in this field of research. Recent infant studies, mostly conducted by von Hofsten and his group (von Hofsten, 1980, 1982, 1983; von Hofsten, Vishton, Spelke, Rosander, & Feng, 1998), constitute an exception. This research has shown that young infants are capable of manually intercepting a (slowly) moving object as soon as they begin to reach for stationary objects (von Hofsten & Lindhagen, 1979) and that their rudimentary interception skills improve markedly between four and eight months of age. Infants' reaching movements have been shown to be predictive in that they are geared toward the future interception point rather than at the object's momentary position (von Hofsten 1980; Clifton, Muir, Ashmead, & Clarkson, 1993). Although infants show anticipation of a future interception point if the object moves linearly, reaching is interrupted if the object moves on a non-linear path (von Hofsten et al., 1998).

Reaching for linearly moving objects has also been investigated with older children and adults. Reaching skills seem to develop quite slowly with respect to accuracy and interception speed and are not fully developed until the teenage years. Reaching movements of adults have been shown to be highly adapted to object speed: Objects that move with high velocity are approached faster than objects moving more slowly even if participants are instructed to reach for the object as fast as possible (Smeets & Brenner, 1995).

But how does the reaching movement change if object motion is unpredictable like in the case of animate objects? More specifically, do adults as well as children adapt their movements to the escape behaviour of a target object and gear them toward the object's momentary position instead of toward an anticipated interception point? To investigate this, we conducted an experiment where participants (10-year-old children and adults) had to intercept a moving object displayed on a computer monitor that moved either linearly or showed an escape behaviour.

[1] Now at: Friedrich-Miescher-Laboratory of the Max-Planck-Society

Participants controlled another virtual object to intercept the target object.

2. Experiment

2.1 Method

Twenty-eight adults and 26 10-year-old children took part in the experiment. Two adults and one child had to be excluded due to technical problems and three adults as well as two children had to be excluded from the analysis because they did not follow the instructions (i.e., they did not try to catch the ball as fast as possible). The data of 23 adults (11 female, 12 male) and 24 children (12 female, 12 male) was analysed. The average age of the adults was 23 years and 8 month (min: 19;1, max: 28;7) and of the children 10 years and 2 month (min: 9;1, max: 11;3).

Participants' task was to intercept a spherical object moving on a computer monitor. In order to intercept the object they had to move a second object that they controlled via a PHANToM™ haptic interface. The target object moved with constant speed (either 17 cm/s or 24 cm/s) starting from the left or right border of the monitor. In a linear condition, the target moved on a straight and horizontal path. In a non-linear condition, the target was programmed to show an escape behaviour, i.e., it changed its direction (with a new direction at a random angle between 75 deg and 105 deg to the left or right of the former direction) as soon as the distance from the participant's object fell below a randomly chosen minimal distance.

The two conditions were presented separately in two experimental blocks. Object speed and direction were varied from trial to trial. To familiarise participants with the respective target behaviour, eight practice trials were presented at the beginning of each block. In the linear condition, eight experimental trials were given; in the non-linear condition, a total of 40 experimental trials were given in eight of which the target moved on a linear path, like in the linear condition with no change of the direction. Only these eight trials were analysed and compared with the eight experimental trials of the linear condition. The participants' catching movements were measured with the PHANToM™ haptic interface.

This action task was followed by a judgement task where only the target speed varied. After the target had left its home-field (marked by a circle around the starting position), participants had to indicate the most suitable angle for the initial sub-movement of the interception response. Two practice trials were followed by four experimental trials for each the linear and non-linear condition separately.

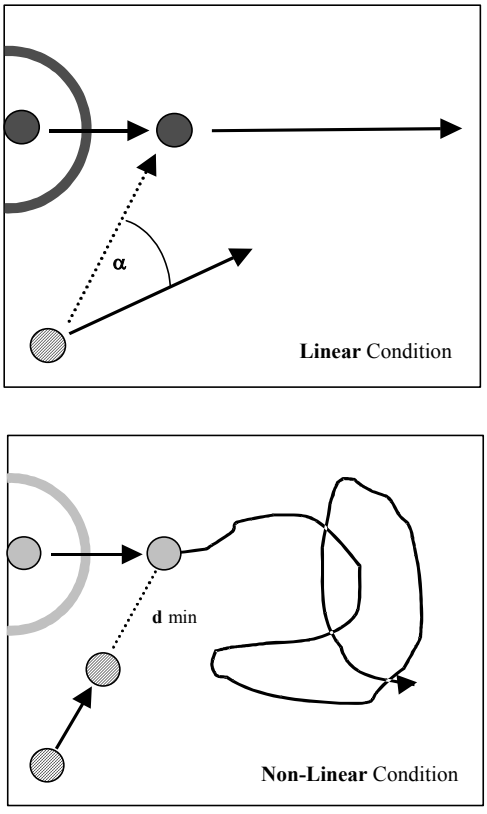

Figure 1. Linear (upper panel) and nonlinear condition (lower panel). In the linear and non-linear condition the target objects are a blue and orange sphere, respectively. The object controlled by the participant was a purple sphere. Its starting position was the left and right lower corner for a homefield of the target on the left and right side, respectively. The circular line around the starting position of the target sphere indicated the home-field. The angle α indicates the initial direction of the reaching movement. The distance dmin was chosen randomly each trial; it indicates the distance at which the escape behaviour started.

2.2 Results

Data of participants' initial direction of movement (relative to the current object position, calculated for the first 100 ms following the movement initiation) and maximum speed of the first sub-movement of each trial were analysed. The initial movement direction provided information whether participants' movements were rather geared toward the target's current position or toward an anticipated interception point. In the judgement task, the estimated angles were analysed. ANOVAs were performed for the action and judgement conditions separately on the within-factors object speed and predictability of object motion (linear vs. non-linear condition) as well as on the between-factor age.

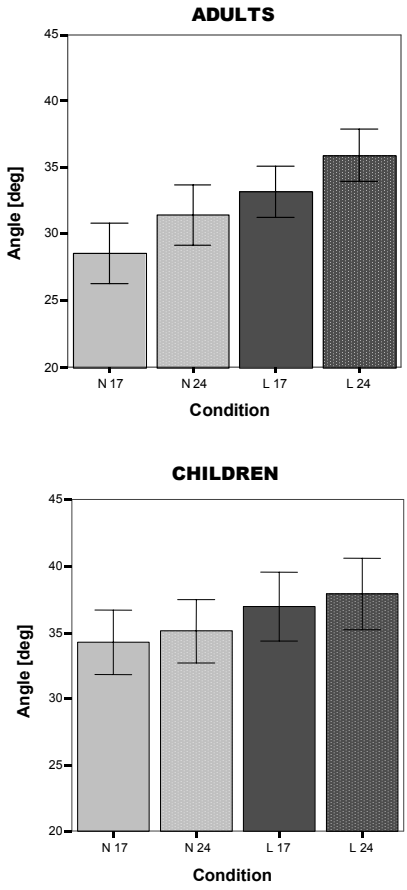

Figure 2. Initial direction in the judgement condition for children and adults (L = linear condition, N= nonlinear condition, 17 and 24 indicate the target speed of 17 cm/s and 24 cm/sec)

2.2.1 Judgement – Initial direction. In the linear condition estimated angles were larger than in the non-linear condition, $F(1, 46) = 9.11$, $p < .01$. Participants aimed further ahead in the linear condition. The estimated angles were also larger for the fast object, $F(1, 46) = 5.08$, $p < .05$. Overall, no age differences were found, $F(1, 45) = 1.71$, $p = .20$).

2.2.2 Action – Initial direction. The initial angle of the interception response varied with the predictability of the target's motion: The angle was larger in the linear condition than in the non-linear condition, $F(1, 45) = 9.15$, $p < .01$. This indicated that participants rather aimed for an anticipated interception point in the linear condition but approached the target object more directly in the non-linear condition. Overall the initial direction did not differ significantly for the high and low target speed, $F(1, 45) = 2.51$, $p > 0.1$. The two way interaction of the factors object speed and predictability of object motion, $F(1, 45) = 5.02$, $p < .05$, as well as the three way interaction with age, $F(1, 45) = 5.91$, $p < .05$, turned out to be significant, however. The initial angle tended to be smaller for the fast object, in contrast to the judgement condition. Children did not show this effect, however, in the non-linear condition.

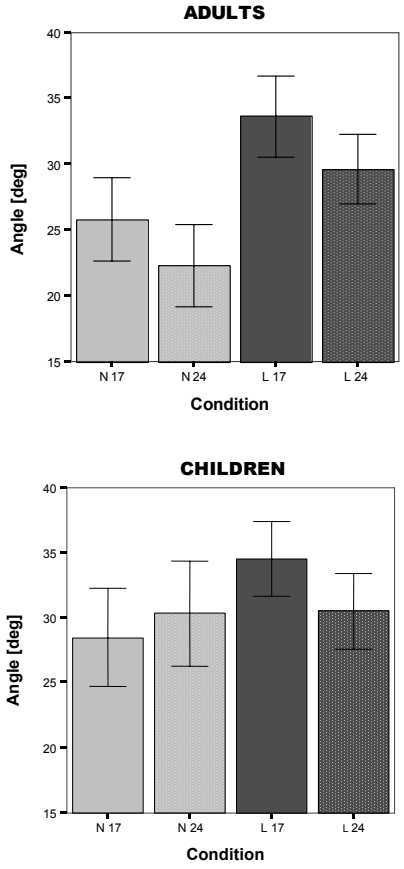

Figure 3. Average produced initial direction in the action condition for children and adults. (L = linear condition, N= nonlinear condition, 17 and 24 indicate the target speed of 17 cm/s and 24 cm/sec).

2.2.3. Action – Maximum speed. The maximum speed of the first sub-movement varied with both object speed and the predictability of object motion. It was higher in the non-linear condition than in the linear condition, $F(1, 45) = 55.23$, $p < .001$, and higher for the fast object than for the slow object, $F(1, 45) = 107.95$, $p < .001$. Overall, adults produced higher movement speeds than children, $F(1, 45) = 5.70$, $p < .05$, but age did not interact with the object speed, $F < 1$ or the predictability of object motion, $F(1, 45) = 1.37$, $p = .25$.

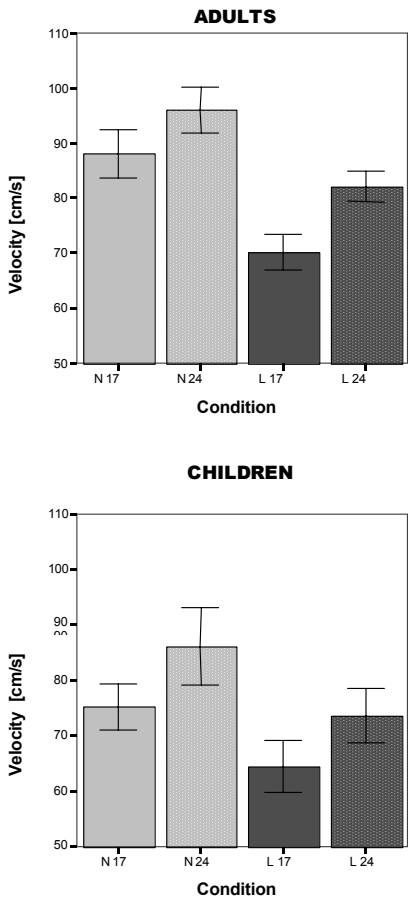

Figure 4. Average produced maximum speed for the first sub-movement for children and adults. (L = linear condition, N= nonlinear condition, 17 and 24 indicate the target speed of 17 cm/s and 24 cm/sec).

3. Discussion

In general, we found different visuomotor control strategies for reaching toward targets moving predictably or unpredictably. The reaching movement differed with respect to both the initial movement direction and maximum speed of the first sub-movement. In the linear condition, participants aimed at an anticipated interception point while, in the non-linear condition, participants approached the object more directly. Participants reached faster for unpredictable than for predictable targets. Additionally adults and children reached faster for the fast object than for the slow object.

Taken together, these results show that participants' reaching movements were adapted to both target speed and predictability of the target motion. Participants used different strategies in the two conditions. In the linear condition, reaching for the target is a simple interception task where the interception point can be anticipated and approached with a velocity tuned to the target speed. In the case of unpredictable objects the anticipation of an interception point is not possible and participants tried to reach for the target much faster and more directly toward the target.

Based on the present results, it appears possible to investigate (implicit) knowledge about the predictability of object motion. In future studies, children's knowledge about animate and inanimate objects could be investigated using our paradigm. Children making mistakes in judging whether an object belongs to the animate or inanimate category, nevertheless, may show different reaching behaviour when asked to catch these objects.

4. References

[1] R. K. Clifton, D. W. Muir, D. H. Ashmead, and M. G. Clarkson. "Is visually guided reaching in early infancy a myth?", *Child Development,* 64, 1993, pp. 1099-1110.

[2] P. W. Dorfman. "Timing and anticipation: A developmental perspective." *Journal of Motor Behavior*, 9, 1977, pp. 67-79.

[3] J. Keogh and D. Sugden (1985). *Movement skill development.* New York, NY: Macmillan.

[4] R. A. Schmidt. *Motor control and learning: A behavioral emphasis* (2nd ed.). Champaign, IL: Human Kinetics, 1988.

[5] J. B. J. Smeets and E. Brenner. Perception and action based on the same visual information: Distinction between position and velocity. *Journal of Experimental Psychology: Human Perception and Performance, 2*, 1995, pp. 19-31.

[6] C. von Hofsten. Predictive reaching for moving objects by human infants. *Journal of Experimental Child Psychology, 30*, 1980, pp. 369-382.

[7] C. von Hofsten. Eye-hand coordination in the newborn. *Developmental Psychology, 18*, 1982, pp. 450-461.

[8] C. von Hofsten. Catching skills in infancy. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 1983, pp. 75-85.

[9] C. von Hofsten and K. Lindhagen. Observations on the reaching for moving objects. Journal of Experimental Child Psychology, 28, 1979, pp. 158-173.

[10] C. von Hofsten, P. Vishton, E. S. Spelke, Q. Feng, and K. Rosander. Predictive action in infancy: tracking and reaching for moving objects. *Cognition, 67*, 1998, pp. 255-285.

[11] H. G. Williams. Perceptual-motor development in children. In C. B. Corbin (Ed.*), A textbook of motor development.* Dubuque, IA: Brown, 1973.