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Age differences in estimating arrival-time

Nicolas Benguigui[a,*], Michael Broderick[b], Hubert Ripoll[c]

[a] *Centre de Recherches en Sciences du Sport, Université Paris-Sud(11), UFR STAPS, Bâtiment 335, 91405 ORSAY Cedex, France*
[b] *Arizona State University, USA*
[c] *University of the Mediterranean, Marseille, France*

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Abstract

The present study examined the accuracy in extrapolating an occluded trajectory in relation to observer age. Adults and children aged 7, 10, and 13 were tested in a prediction-motion task which consisted of judging, after the occlusion of the final part of its path, the moment of arrival of a moving stimulus towards a specified position. Results showed that children as young as 7 years old are able to use the same strategy as adults in the extrapolation of an occluded moving object. However, accuracy in responses improves most significantly for occlusion times equal to or more than 400 ms and this improvement occurs mainly between 7 and 10 years of age. This confirms that children are less efficient in performing the computations necessary to extrapolate in time an occluded trajectory.

Keywords: Arrival-time; Motion extrapolation; Prediction-motion task; Development

A large number of studies have shown that children have more difficulty than adults when trying to accurately coordinate their actions with the displacement of moving objects in real-world tasks such as intercepting or catching a ball (e.g., [1,24]) and crossing a road (e.g., [11]). It is reasonable to assume that some of the age-related differences in these tasks come from an inability to correctly estimate the arrival-time (AT) of the moving object at the position where contact will occur (e.g., [22]).

One method currently used to study the accuracy of AT estimates is the occlusion method, which involves the use of prediction-motion (PM) tasks (e.g., [3,23]). These tasks consist of presenting a moving object that is occluded just before it reaches the observer or a specified position. The observer is required to make a simple response (e.g., press a button) that will coincide temporally with the moving object's immediate arrival at the observer's position or another specified position in space. The numerous studies carried out in this field have shown that a linear relationship exists between estimates of the arrival-time after the occlusion and actual arrival-time (e.g., [5,22]). According to Yakimoff et al. [26], this relationship can be expressed by the equation: $T_r = \alpha(T_a) + \theta$, where T_a is the actual arrival-time of the moving object, T_r is the response time between the occlusion and the response (which corresponds to the participant's estimate of T_a), and α and θ are the two parameters characterizing the accuracy of extrapolation. It has generally been observed that the slope α are much lower than 1 and the intercept θ are greater than zero. This means that participants underestimate the AT for the longer occlusions and overestimate the AT for the shorter occlusions. Generally, the transition point between under- and overestimations is 1 s (e.g., [15,21]).

Yakimoff et al. [26] pointed out that the linear model would only be applicable for occlusions greater than or equal to 200 ms. In making this assertion, they took into account the duration of a visuo-motor delay during which information about the time remaining before the arrival of the moving object could not be used to coordinate the response. Following this assumption, one might infer that for occlusions shorter than 200 ms, the accuracy of responses should not be differ-

* Corresponding author. Tel.: +33 169 15 43 11; fax: +33 169 15 62 37.
E-mail address: nicolas.benguigui@staps.u-psud.fr (N. Benguigui).

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ent from the accuracy in coincidence-timing tasks without occlusion.

However, this assumption would be unwarranted if, as some authors have suggested, the visuo-motor delay is shorter in coincidence-timing actions than 200 ms. For example, Lee et al. [12] calculated theoretical visuo-motor delays on the order of 50–135 ms in their ball-striking task. Using a ball-catching task in which the final part of the trajectory was occluded, Whiting et al. [25] showed that the catching performances degraded when occlusion was equal to or greater than 100 ms. This suggested that the information available up to this time is used to control the action. Bootsma and van Wieringen [4], in a table-tennis ball-striking task, as well as Savelsbergh et al. [20], in a catching task, observed that variability in movement was minimal at about 100 ms before contact. These authors concluded that this phase of minimal variability corresponds to the end of the control of the action and that the duration of this interval might correspond to a visuo-motor delay. Consequently, it can be suggested that the accuracy in AT estimations could also decrease with occlusions shorter than 200 ms.

In order to explain the relative inaccuracy in PM tasks, some authors have taken a specific interest in the processes involved in extrapolations made after a visual stimulus is occluded (e.g., [6,10,14,23]). Two types of operation are generally proposed to explain performance in PM tasks [6,14]. The first type posits cognitive temporal extrapolation with both perception of AT from optical information and utilization of an internal clock that counts down the estimated AT such that, when a time equal to this time has elapsed, a response can be produced (e.g., [23]). The second type posits cognitive motion-extrapolation operations substituting for the absence of visual information. These operations involve a cognitive or internal representation of the trajectory permitting extrapolation of the object's displacement after its occlusion [9,22]. DeLucia and Lidell [6] suggested that cognitive motion-extrapolation operations imply utilization of mental images and/or ocular pursuit movements. The respective implication of these two classes of mechanisms has not yet been fully developed and needs further research. However, the findings of the existing PM research suggest at least that higher order cognitive processes (or cognitive extrapolation) are required in such tasks.

Whereas many studies have been conducted with adults, rarely have occlusion procedures been used to address the development of motion prediction in children. Dorfman's research [7] is therefore of interest. In this study, six different populations (ages 6–7, 8–9, 10–11, 12–13, 14–15 and 18–19) were tested in a task that required participants to displace a luminous spot with a cursor on an oscilloscope along a rectilinear trajectory in order to intercept another luminous spot moving on a transversal axis. In the initial phase, the participants performed 40 trials with a stimulus visible throughout its entire displacement (i.e., for 700 ms). In the next 20 trials, stimulus displacement was occluded after 90 ms of presentation for the remainder of its path (i.e., for 610 ms). Dorfman observed that occlusion of the final part of the trajectory had less effect on accuracy in the participants aged 14–15 and 18–19 than in younger children. As an explanation, Dorfman suggested that the cognitive processes involved to compensate for the disappearance of the moving objects were likely to develop later than those required when displacement of the moving object was not occluded.

Using a similar approach, Ripoll [18] corroborated these results. In this experiment, children of 7, 9, 11 and 13 years of age had to estimate the moment of arrival of a moving stimulus at a target in six different visual conditions. In one of these conditions, the trajectory was presented in its entirety, while in the other five conditions the last part of the trajectory was occluded with occlusion times of 48, 96, 192, 288, and 384 ms. The results showed that, for 7- to 9-year-olds, the longer the occlusion, the less accurate the responses and the greater the difference in accuracy between them and the other groups. Further analysis showed that 7-year-olds tended to alternate underestimation and overestimation of the AT, while 9-year-olds overestimated systematically. For the 11-year and 13-year-olds, response accuracy was the same across conditions and responses were slightly overestimated. The level of errors did not increase for occlusions greater than or equal to 96 ms. The only differences between the two older groups were the variability in the AT estimates, which decreased slightly for participants between 11 and 13 years of age. In sum, this study showed that accuracy of AT estimates improves mainly between 7 and 11 years of age. However, it was not possible to examine the results in connection with the model proposed by Yakimoff et al. [26] as no distinction was made between occlusions less than and greater than 200 ms and as the occlusions greater than 200 ms were insufficiently long.

The present study was designed to delve further into these issues by examining the development of the perceptual and cognitive processes involved in AT estimates. More precisely, we referred to the linear model of Yakimoff et al. [26] in order to describe the development of accuracy in PM tasks. Following the distinction of Yakimoff et al. [26], we used occlusions greater than and less than 200 ms in order to determine whether the accuracy in PM task differs according to age. We expected small developmental differences or no differences for short occlusion durations in which the processes are supposed to be perceptually driven. In contrast, we expected large differences for longer occlusion durations which require cognitive extrapolation.

Three groups of 16 males aged 7 (M in years = 7.1, S.D. in years = 0.3), 10 (M = 9.9, S.D. = 0.7) and 13 (M = 13.2, S.D. = 0.7) years old participated in this experiment. A fourth group of 16 male adults (M = 25.0, S.D. = 4.2) also took part. All participants reported normal or corrected-to-normal vision. This experiment was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from the participants and from the parents of the children who participated to this experiment.

The experimental situation required the participants to estimate the arrival moment of an apparent motion at a target. The apparent motion was generated on a 4-m-long simulator by the sequential switching of 200 red LEDs positioned at 2 cm intervals. The illuminated stimulus moved left to right toward a target situated at the extreme end of the ramp. The target was represented by two green LEDs, placed above and below the last red LED. The illumination of the LEDs, trial onset, and data acquisition were synchronized using Labview software on a PC (the same system was previously used by [3]).

Participants sat 2 m away from the apparatus, directly in front of and facing the target. They initiated each trial by pressing a button with their left hand and were required to press another button with their right hand when they thought that the moving stimulus had reached the target. Response accuracy (in ms) was defined as the time difference between the participant's estimate and the actual AT. Early responses were marked with a negative sign and late responses with a positive sign.

During the test, stimulus motion could be presented either up until the arrival at the target or occluded before reaching it. The occlusion was produced by the non-illumination of the LEDs situated in the "occlusion zone." Testing consisted of seven conditions with occlusion times of 0, 67, 133, 200, 400, 600 and 800 ms. For each condition, the moving stimulus speed was 2 m/s and the stimulus was presented for 600 ms before the arrival at the target for the condition without occlusion and before the occlusion for the occlusion conditions. The stimulus-presentation duration was set at 600 ms in order to be significantly greater than the duration for which accuracy in PM tasks begins to decrease. A preliminary experiment had shown that the viewing time had no effect on extrapolation when it was above 240 ms for either adults or children aged between 7 and 13 ([2]; see also [19]).

After having been informed by the experimenter of the purpose of the experiment, the participants had a training period using both occluded and non-occluded conditions. During the training, the moving stimulus speed was 1.7 m/s and presentation time of the stimulus was 600 ms. In the occluded condition, occlusion time was 300 ms. The speed and the occlusion time during training were different from the speeds and occlusion periods used in the experiment to prevent specific learning to any of the experimental conditions. There were six consecutive trials in each condition. In each trial, the participants were given qualitative knowledge of results ("too early", "too late" or, when errors ranged from −50 to +50 ms, "correct response"). The participants practiced two blocks in each condition. To ensure that the participants had a good idea of the requirements of the task, we required two "correct responses" in each condition. All participants met this requirement after the two blocks of practice.

Following the training period, the participants performed seven randomly presented blocks of six trials corresponding to each of the seven occlusion conditions. Before performing each block, the participants let the first trajectory pass without giving a response, and thereby got acquainted with the appearance and occlusion zones of the moving stimulus. So as to avoid response improvement due to prior knowledge of sequence timing, no feedback was given during the experiment.

For each occlusion condition, constant error (CE), absolute error (AE), and variable error (VE) were calculated on the recorded responses.

In order to address the question concerning whether extrapolations were carried out in the same way for short (0–200 ms) and long (200–800 ms) occlusions, in accordance with the linear model of Yakimoff et al. [26], we calculated two linear regressions from the AT estimates of each participant. For the first (0–200 condition), independent variables corresponded to the four shorter occlusion times (i.e., 0, 67, 133 and 200 ms) and the dependent variables to the average AT estimates for each condition. For the second (200–800 condition), the same analyses were applied to the longer occlusions (i.e., 200, 400, 600 and 800 ms).[1] For each participant, these calculations yielded two slopes, two intercepts and two coefficients of correlation corresponding, respectively, to the shorter and the longer occlusions.

CE, AE and VE were separately analyzed in a 4 × 7 (Age × Occlusion) mixed ANOVA with Age (7, 10, 13 and adults) as a between-subjects factor and Occlusion time (0, 67, 133, 200, 400, 600 and 800 ms) as a within-subjects factor. The coefficients of correlation (transformed to Fisher Z scores [8]), the slopes, and the intercepts obtained from the linear regression were analyzed in a 4 × 2 (Age × Occlusion) mixed ANOVA with Age (7, 10, 13 and adults) as a between-subjects factor and Occlusion time (0–200 and 200–800 ms) as a within-subjects factor. A Newmann–Keuls post hoc test was used for comparison of the means. An alpha level of 0.05 was used for all statistical tests.

The ANOVA on CE revealed a significant main effect of Occlusion, $F(6, 360) = 12.18$ (Table 1). Post hoc comparisons revealed that CE in occlusion conditions 600 and 800 ms (negative bias) was significantly different from all other conditions (positive bias). In addition, the magnitude of CE was greater in the 200 ms condition than in the 0 ms condition. The effect of Age ($F[3, 60] < 1$) was not significant, nor was the Age × Occlusion interaction ($F(18, 360) < 1$).

The ANOVA on AE indicated significant main effects of Age, $F(3, 60) = 20.55$, and Occlusion, $F(6, 360) = 72.06$, as well as an Age × Occlusion interaction, $F(18, 360) = 2.72$ (Table 1; Fig. 1). The post hoc analysis of the Age × Occlusion interaction showed that the 7-year-olds were less accurate than the three older groups only for occlusion conditions greater than or equal to 400 ms (Fig. 1). The 10-year-old group was not different from the two older groups for any condition. The post hoc analyses also showed that, for the two

[1] The 200 ms occlusion condition was used for both regression lines because this duration is described as the transition between short and long occlusion time (e.g., [26]).

Table 1
CE, AE and VE according to age and occlusion conditions

	Occlusion time						
	0	67	133	200	400	600	800
Constant error							
7 years	20	62	61	66	47	7	−33
10 years	−11	18	17	50	19	−25	−69
13 years	0	20	38	57	20	−3	−27
Adults	−1	18	15	14	6	−31	−68
Absolute error							
7 years	82	108	98	142	205	217	257
10 years	51	73	77	106	99	117	140
13 years	38	51	66	76	110	141	177
Adults	37	56	57	69	91	114	164
Variable error							
7 years	86	111	94	129	152	175	198
10 years	59	66	77	106	95	126	140
13 years	43	43	54	52	76	100	134
Adults	32	44	46	64	62	77	102

younger groups, AE in the non-occlusion condition were not significantly different from AE in the two shortest occlusion conditions (67, 133) but were different from AE in the other conditions (200, 400, 600, 800). For the 13-year-old group and the adults, AE in the non-occlusion condition were not significantly different from AE in the three shortest occlusion conditions (67, 133, 200) but were different from AE in the longer conditions (400, 600, 800). Thus, occlusion induces a decrease of accuracy for duration equal or superior to 200 ms as was suggested by Yakimoff et al. [26].

The ANOVA on VE revealed significant main effects of Age, $F(3, 60) = 21.09$, and Occlusion, $F(18, 360) = 33.66$, were found. Post hoc comparisons for the Age effect indicated that participants' variability decreased between the ages of 7 and 10 years, and between 10 and 13 years. There was no significant difference between 13-year-olds and adults. Post hoc comparisons for the Occlusion effect indicated that VE in the non-occluded condition was significantly different from

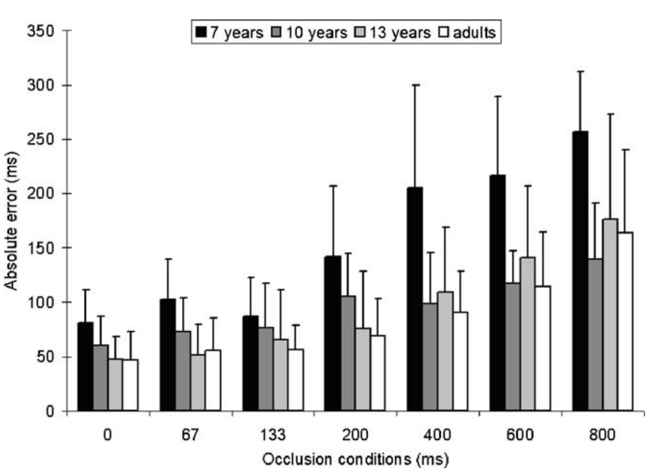

Fig. 1. AE according to age and occlusion conditions. The analysis of variance indicated a main effect of age and a main effect of occlusion and an Age × Occlusion interaction.

Table 2
Average slopes, intercepts and coefficients of correlation (r, raw data), according to age, for the linear regressions 0–200 and 200–800

Population	0–200			200–800		
	Slopes	Intercepts	r	Slopes	Intercepts	r
7 years	1.24	36	0.924	0.83	105	0.962
10 years	1.28	−6	0.932	0.80	94	0.986
13 years	1.28	4	0.976	0.86	81	0.994
Adults	1.05	7	0.981	0.86	51	0.994
Mean	1.20	10	0.953	0.84	83	0.984

VE in the four longer occlusion conditions (200, 400, 600 and 800). There were no interaction effects involving VE.

In order to assess the linear model of Yakimoff et al. [26], the three components of the linear regressions were analyzed (see Table 2).

The [4 × 2 (Age × Occlusion)] ANOVA on slopes revealed a significant main effect of Occlusion, $F(1, 60) = 96.06$). The slopes were higher for the 0–200 ms condition than for the 200–800 ms condition (1.22 versus 0.84, respectively). There was no main effect of Age ($F(3, 60) = 2.04$), but the interaction between Age and Occlusion ($F(3, 60) = 2.60$) was significant. Post hoc analyses showed that there was no difference between the four groups for the long occlusions while the adult group was different from the three children groups for short occlusions (1.05 versus 1.24, 1.28 and 1.28). This difference is probably due to the fact that some children in each group systematically waited for the disappearance of the stimulus before beginning an (inappropriate) extrapolation of its displacement. Indeed, after the experiment, three children explicitly reported doing this. This strategy resulted in late responses for the shortest occlusion conditions (67, 133, 200) for the three groups of children (which appear in CE without significant difference, see CE in Table 1) and could explain slopes greater than 1. To confirm this interpretation, we calculated the median of each group. Results showed medians of 1.10, 1.20, 1.17 and 1.08 (corresponding to the four age groups from the younger to the older, respectively) that were very close to each other. Differences in the means are probably due to a few children who had very high slopes (four 7-year-olds, five 10-year-olds and four 13-year-olds had slopes above 2, whereas no adult was above 1.5).

The ANOVA on intercepts indicated a significant main effect of Occlusion, $F(1, 60) = 32.33$ with smaller intercepts in the 0–200 ms condition than in the 200–800 ms condition (10 versus 83, respectively). There was no main effect of Age ($F(3, 60) = 1.25$) and no interaction between Age and Occlusion ($F(3, 60) < 1$).

The ANOVA on coefficients of correlation revealed a significant main effect of Age ($F(3, 60) = 7.18$). Post hoc comparisons of the Age effect indicated that 7- and 10-year-old children had lower coefficients of correlation than the two older groups. In addition, the ANOVA revealed a significant main effect of Occlusion ($F(1, 60) = 8.01$). The coefficients of correlation were higher for the 200–800 ms condition than for the 0–200 ms condition. There was no interaction between Age and Occlusion ($F(3, 60) < 1$).

The purpose of this study was to examine how the ability to extrapolate in time an occluded moving object develops with age. The results confirmed those obtained by Dorfman [7] and Ripoll [18] in which the improvement in estimates was found to occur between the ages of 7 and 13 years. The use of more numerous occlusion conditions (up to 800 ms) and the distinction between short and long occlusions (under and above 200 ms) provide a broader picture of the developmental processes involved in extrapolation.

As was hypothesized, no difference appeared between children and adults in short occlusion conditions in which the processes are supposed to be perceptually driven. In contrast, large differences appeared for longer occlusion durations, which require cognitive extrapolation (see the Age × Occlusion interaction for AE in Fig. 1).

The results confirm that 200 ms is the threshold for which extrapolation mechanisms are necessary [26]. For all age groups, analyses of both AE and VE showed significantly more error for occlusion durations equal to or greater than 200 ms than for the non-occlusion condition. This was also confirmed by the regression analyses which showed very different slopes for short and long occlusion. For short occlusions, the occlusion itself is not really a factor as the occlusion time corresponds to a visuo-motor delay. The response then can only be as precise as in situations without occlusion. The adults' mean slope was 1.05 which was less than that of the three younger groups (1.27). The slopes of the children were likely due to the inappropriate extrapolation strategy of several children in each group. Responses had to be produced in the shorter occlusion conditions as if there were no occlusion. The children's expectation of the occlusion and their use of an extrapolation strategy in such conditions consequently resulted in delayed responses.

For the longer occlusions, it appears that the estimates were made using the same extrapolation strategy regardless of participant age, as the analyses performed from the linear regressions obtained for each age group showed no differences in the slopes and intercepts (see Table 2). Moreover, these values (ranging from 0.80 to 0.86) were consistent with those generally observed in studies using PM tasks (see [5] for a review). The age-related differences for longer occlusions concerned the coefficients of correlation and the magnitude of errors. This difference suggests that in the course of development children produce AT estimates that are progressively more in accordance with the linear model of Yakimoff et al. [26].

In connection with the literature on the PM task, two hypotheses can be proposed to explain the results of the young children. First, it can be suggested that the children have difficulty in mastering cognitive temporal-extrapolation processes. Following this hypothesis, one might be inclined to compare these results with those obtained in research studying the development of the ability to estimate duration. The mastering of this ability across development has been extensively studied since the seminal works of Piaget [16,17] and constantly reexamined over the last decades (see [13] for an overview). Results have shown that the ability to estimate duration is a late achievement in the course of development and completely mastered by the age of 11. These data are in accordance with the chronology of development that we found in this experiment. The second explanation could be connected to a difficulty in using a cognitive motion extrapolation. As DeLucia and Lidell [6] have underscored, this process requires imagery, eye movements, and attentional shift in order to obtain a cognitive representation of the object's motion. It would not be surprising if mastering such operations occurred gradually over the course of development. Both hypotheses require testing in future research.

In sum, the results of this experiment show that, with age, participants improve their performance in PM tasks at two levels, corresponding to shorter and longer occlusion times. For short occlusions (≤200 ms), the responses have to be produce as if there were no occlusion [27]. Some children are perhaps less accurate than other children and adults because they use a situation-inappropriate cognitive extrapolation strategy. For the longer occlusion times (≥200 ms), children as young as 7 years of age are capable of using the same type of strategy as adults to cope with disappearance of the moving object and to extrapolate in time the occluded trajectory (cf. [26]). However, it also appears that response accuracy improves with age. This improvement is due to enhanced cognitive processes necessary when extrapolating in time the displacement of the moving stimulus. Such processes remain to be clearly identified.

References

[1] C. Bard, M. Fleury, M. Gagnon, Coincidence-anticipation timing: an age-related perspective, University of South Carolina Press, Columbia, SC, 1990.
[2] N. Benguigui, Effet de la pratique d'un sport de balle sur le développement des processus perceptifs impliqués dans les actions d'interception [Effects of Tennis Practice on the Coincidence Timing Accuracy of Adults and Children], Unpublished doctoral dissertation, University of Poitiers, France, 1997.
[3] N. Benguigui, H. Ripoll, M.P. Broderick, Time-to-contact estimation of accelerated stimuli is based on first-order information, J. Exp. Psychol.: Hum. Percept. Perform. 29 (6) (2003) 1083–1101.
[4] R.J. Bootsma, P.C.W. Van Wieringen, Timing an attacking forehand drive in table tennis, J. Exp. Psychol.: Hum. Percept. Perform. 16 (1990) 21–29.
[5] J.K. Caird, P.A. Hancock, The perception of arrival time for different oncoming vehicles at an intersection, Ecol. Psychol. 6 (1994) 83–109.
[6] P.R. DeLucia, G.W. Lidell, Cognitive motion extrapolation and cognitive clocking process in prediction motion tasks, J. Exp. Psychol.: Hum. Percept. Perform. 24 (1998) 901–914.
[7] P.W. Dorfman, Timing and anticipation: a developmental perspective, J. Motor Behav. 9 (1977) 67–79.
[8] R.A. Fisher, The Design of Experiments, Oliver & Boyd, Edinburgh, 1942.

[9] R.J. Jagacinski, W.W. Johnson, R.A. Miller, Quantifying the cognitive trajectories of extrapolated movements, J. Exp. Psychol.: Hum. Percept. Perform. 9 (1983) 43–57.
[10] M.K. Kaiser, L. Mowafy, Optical specification of time-to-passage: observers' sensitivity to global tau, J. Exp. Psychol.: Hum. Percept. Perform. 19 (1993) 1028–1040.
[11] D.N. Lee, D.N. Young, C.M. McLaughlin, A roadside simulation of road crossing for children, Ergonomics 27 (1984) 1271–1281.
[12] D.N. Lee, D.S. Young, P.E. Reddish, S. Lough, T.M.H. Clayton, Visual timing in hitting an accelerating ball, Q. J. Exp. Psychol. 35A (1983) 333–346.
[13] I. Levin, D. Zakay, Time and human cognition. A life span perspective, Elsevier Science Publishers B.V, Amsterdam, North-Holland, 1989.
[14] D.R. Lyon, L.G. Waag, Time course of visual extapolation accuracy, Acta Psychol. 89 (1995) 239–260.
[15] M.P. Manser, P.A. Hancock, Influence of approach angle on estimates of time-to-contact, Ecol. Psychol. 8 (1996) 71–99.
[16] J. Piaget, The Child's Conception of Time, Basic Books, New York, 1969 (A.J. Pomerans, Trans.; original work published 1946).
[17] J. Piaget, The Child Conception of Movement and Speed, Basic Books, New York, 1970 (G.E.T. Holloway, M.J. Mackenzie, Trans.; original work published 1946).
[18] H. Ripoll, The development of judging time-to-arrival judgment in children, NASPSA Abstracts Conference, Sport Exerc. Psychol. 16 (1994) 97.
[19] D.A. Rosenbaum, Perception and extrapolation of velocity and acceleration, J. Exp. Psychol.: Hum. Percept. Perform. 1 (1975) 395–403.
[20] G.J.P. Savelsbergh, H.T.A. Whiting, R.J. Bootsma, 'Grasping' tau, J. Exp. Psychol.: Hum. Percept. Perform. 17 (1991) 315–322.
[21] W. Schiff, M. Detwiler, Information used in judging impending collision, Perception 8 (1979) 647–658.
[22] W. Schiff, R. Oldack, Accuracy of judging time to arrival: effects of modularity, trajectory and gender, J. Exp. Psychol.: Hum. Percept. Perform. 16 (1990) 303–316.
[23] J.R. Tresilian, Perceptual and cognitive processes in time-to-contact estimation: analysis of prediction motion and relative judgment tasks, Percept. Psychophys. 57 (1995) 231–245.
[24] K. Williams, Development of object interception, in: J.E. Clark, J.H. Humphrey (Eds.), Advances in Motor Development Research, AMS Press, Baltimore, 1986, pp. 201–217.
[25] H.T.A. Whiting, E.B. Gill, J.M. Stephenson, Critical time intervals for taking in flight information in a ball-catching task, Ergonomics 13 (1970) 265–272.
[26] N. Yakimoff, S. Mateff, W.H. Erhenstein, J. Hohnsbein, Motion extrapolation performance: a linear model approach, Hum. Factors 35 (1993) 501–510.
[27] N. Yakimoff, L. Mitrani, N. Bocheva, Estimating the velocity of briefly presented moving stimuli., Acta Psychol. Pharmacol. Bulg. 7 (1981) 72–79.