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AN ASSESSMENT OF REACTION TIME DEVELOPMENT IN FEMALES USING POLYNOMIAL REGRESSION ANALYSIS

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ABSTRACT

Purpose. The objective of this study was to determine the level and rate of change of reaction time during the developmental period from early childhood to early adulthood. Polynomial regression analysis was applied to determine the age at which the best reaction time results are achieved. **Methods.** The study involved 550 females between the ages of 7 and 20 years. Participants completed a computer test measuring simple reaction times to visual and auditory stimuli and choice reaction time during the ontogenetic developmental period. **Results**. Analysis of the results for age group distinguished two sub-periods of reaction time dynamics: a progressive increase throughout the developmental period followed by a plateau phase. This was evident for all reaction time measures (simple and choice) particularly in the case of that data collected empirically. **Conclusions.** Best reaction times to visual and auditory stimuli were approximately at the age of 17 years. In turn, quickest choice reaction time was approximately one year earlier in life. The most dynamic increase in the results of both simple reaction times was between the age of 7 and 8 years, whereas for choice reaction time this was between 10 and 11 years of age.

Key words: simple reaction time, choice reaction time, coordination, Polish rural population

Introduction

Reaction time, also known as response time, is considered to be a useful indicator in gauging the speed and effectiveness of decision-making ability. Its importance has led to it being systematically studied for almost 150 years [1]. Reaction time is critical in a number of sports (the sprint start, during a tennis rally, in badminton) and a very important component in efficiently performing numerous activities of daily living (driving a car). In the modern classification system of motor skills and abilities, reaction time is associated with the group of motor coordination skills [2, 3]. It is typically defined as the time that elapses between the moment a stimulus is presented to the end of a specific physical response [4, 5] and therefore sometimes termed as absolute reaction time. It underpins the ability to quickly initiate and execute a targeted, quick movement in response to a specific signal that may involve the entire body or only a part thereof.

Reaction time is dependent on many factors, including sex, age, the number and type of stimuli presented, concentration ability, physical fitness level, the length of one's athletic career, and overall health [6–8]. Numerous studies have indicated that reaction time progressively develops until approximately 20 years of age. Afterwards, reaction time begins to gradually increase until reaching 50–60 years of age after which it begins to deteriorate substantially [9, 10].

The primary objective of this study was to determine the age at which females present the best results in tests determining reaction time as well as estimating the kinetics and dynamics of the development of reaction time during ontogenesis. In light of the above, the study aims were guided by the following research questions:

1. What are the developmental kinetics of reaction time during the developmental period from early childhood to early adulthood?
2. What is the rate of change in reaction time during this period?
3. At what age do females present the best results in reaction time?
4. What are the peak results depending on the type of reaction time?

Material and methods

This study was based on data from tests measuring simple reaction times to visual and auditory stimuli and choice reaction time conducted between 2006 and 2012. The sample population included 550 females between 7 and 20 years of age who grew up in rural areas located near the city of Kraków, Poland. Analysis was performed on longitudinal data collected from primary school girls between 7 and 11 years of age and the cross-sectional results of females approximately 14 (attending middle school) and 20 (attending university) years old. The participants were divided into seven groups based on their chronological age (Tab. 1). The study received the approval of the Bioethics Committee of the Regional Medical Board in Kraków, Poland.

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Tests measuring reaction time were performed using custom software using a mouse connected to a laptop computer (Toshiba, Japan) with a 14.1" LCD monitor set at a resolution of 1024 × 768 pixels. Each participant was informed about the study's purpose and procedure and provided their informed consent or the consent of a parent or legal guardian. The participants were familiarized with the test protocol by completing a number of trials which were discontinued once the examiner observed that the participant thoroughly understood all test instructions. Testing was always performed in a separate room free of disturbances. For the school-aged children testing was typically conducted at their school in their school counselor's room, whereas for the university students the test was administered at the Department of Anthropomotorics at the University of Physical Education in Kraków. All testing was performed by the head author of this study between 08:00 and 14:00. During testing a number of chairs of different heights were made available so as to allow for the most comfortable seating position.

Testing consisted of measuring simple reaction times to visual and auditory stimuli and choice reaction time in milliseconds (ms). For simple reaction time 10 stimuli were were used whereas for choice reaction time 20 stimuli. The test procedure was as follows:

– for simple reaction times to visual and auditory stimuli the index finger of the right hand rested on the left mouse button, the protocol was for the participant to click the mouse button as quickly as possible in response to a visual or auditory cue; the results of the 10 trials were averaged after discarding the two most extreme outliers.

– choice reaction time required the participant to click the left or right mouse button as above but in response to either seeing white square or hearing a beep sound, respectively, in the event of a mistake the participant had to click the correct button as fast as possible; the results of the 20 trials were averaged after discarding the two most extreme outliers.

A series of pilot studies were performed to verify the reliability and validity of the above computer-testing method. Pearson's correlation coefficients (PCC) was calculated for the results from two consecutive series of tests (on two consecutive days separated by a one-day break), findings values of 0.60 for choice reaction time, 0.62 for auditory reaction time, and 0.92 for visual reaction time [11].

In the present study, only absolute reaction time was recorded as the total measure that includes a sensory and motor component. It is determined by latent reaction time (RT) plus movement time (MT). Factors that may affect latent time include initial notice of the stimulus followed by recognition, the decision-making process, the time needed to initiate an action, and the transfer of information from the brain to the effector [1]. Therefore, the present study recorded the time between the presentation of a stimulus until the moment the computer mouse was clicked. Hence, this is how 'simple reaction time' and 'choice reaction time' are to be understood in this paper. Although this is a simple measure that does not require the use of electromyography, it is particularly important in sports as well as medical research.

Statistical analyses included calculating descriptive statistics for the results for chronological age and each of the reaction time measures. Polynomial regression was applied to determine at what chronological age were the best results achieved for each of the reaction time measures. In addition, regression analysis was also performed to determine the best overall result for the reaction time measures. This allowed indicators for both the progressive development and growth rate of reaction time to be calculated (in % compared with the results from the first year). A value of 100% was assumed for reaction time measures at 7 years of age [12].

Results

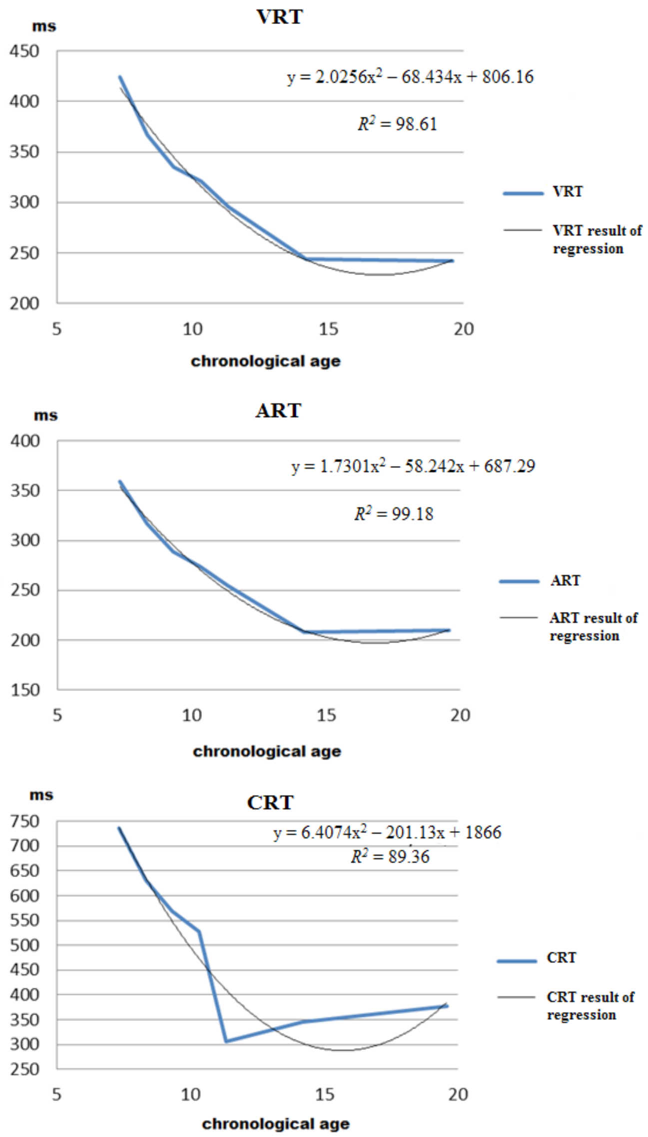
The analyzed reaction time measures in the group of females for chronological age are presented in Table 1. This table also presents the reaction time results based on a second-order polynomial regression model. Analysis of the arithmetic means (both from the collected results and those estimated by regression analysis) found that the development of reaction time could be divided into two sub-periods of reaction time dynamics: a progressive increase throughout the developmental period followed by a plateau phase (in the last age group). This was evident for all reaction time measures (simple and choice) particularly in the case of the empirically collected data.

Analysis of arithmetic means of the results in Table 1 finds that the best results for the reaction time measures fell somewhere between the ages of the middle school and university students. Therefore, a second-order regression equation was used in order to better estimate the quickest mean reaction times and at what age they are obtained.

The level and growth rate of the reaction time measures together with the polynomial regression equations are presented in Figure 1. It was found that the regression equations for visual and auditory reaction times almost fully coincided with those obtained with the empirically collected data from each chronological age group. This is particularly evident between the age range of 7 to approximately 15 years for visual and auditory reaction time. A good fit of the actual data to the regression model was also confirmed by the high R^2 values. The proposed model accounted for 98–99% of variability for visual and auditory reaction time. However, the coefficient of determination for choice reaction time as estimated using regression analysis was found to be slightly lower, where a $R^2 = 0.8936$ indicated that the proposed model

Table 1. Arithmetic means of reaction times (ms) for the analyzed chronological age groups

Chronological age group	Size n	Visual reaction time		Auditory reaction time		Choice reaction time	
		Test	Regression analysis	Test	Regression analysis	Test	Regression analysis
		$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
7 ($\bar{x}$ = 7.30)	94	424.38	399.78	359.52	342.12	736.36	689.75
8 ($\bar{x}$ = 8.30)	94	366.63	375.33	316.59	321.27	630.67	629.07
9 ($\bar{x}$ = 9.30)	94	334.84	350.88	288.46	300.42	569.02	568.39
10 ($\bar{x}$ = 10.30)	94	320.93	326.42	273.58	279.57	527.54	507.71
11 ($\bar{x}$ = 11.30)	94	295.56	301.97	255.06	258.73	304.96	447.03
Middle school students ($\bar{x}$ = 14.20)	30	243.50	231.45	207.50	198.60	345.60	272.04
University students ($\bar{x}$ = 19.58)	50	242.12	215.56	210.16	192.10	378.08	340.08



VRT – visual reaction time, ART – auditory reaction time, CRT – choice reaction time

Figure 1. Reaction time as a function of age during the developmental period

explained only 89% of variability. Nonetheless, the second-order regression equations can accurately determine the age and level at which the best reaction time measures are obtained. The corresponding data are presented in Table 2.

Based on this analysis, it can be concluded that the best results for visual and auditory reaction times are reached at approximately 17 years of age. However, the best results for choice reaction time occur approximately one year earlier in life. Analysis of the data when categorized by the quickest results found auditory reaction time to be fastest (197 ms), then visual (228 ms), and finally choice (287 ms). Furthermore, based on the polynomial regression analysis and the collected data it can be expected that all reaction times begin to plateau between 16–17 and 20 years of age.

As mentioned previously, the data gathered from participants aged between 7 and 11 years were attained from a longitudinal study. This allowed for an assessment of the progression as well as the rate of change of each of the reaction time measures, where a value of 100% was assumed for the results achieved at 7 years of age (Tab. 3).

The most dynamic improvement in both visual and auditory reaction time results was observed between the ages of 7 and 9, amounting to 14% and 12%, respectively, depending on the type of reaction analyzed. On the other hand, the rate of change between 8 and 9 years of life is smaller, being 7–8% compared with the results obtained in the previous year. From the age of 11 the rate of change significantly decreases, averaging approximately 4% per year. In turn, the results in the reaction time tests between the 14-year-old and 20-year-old participants were found to be at a similar level. Slightly different data was obtained in the results of choice reaction time. In this case, the most dynamic rate of change was observed between 10-year-olds and 11-year-olds (30%). A relatively large increase (14%) was also observed between 7 and 8 years of age. As a whole, the total improvement in visual

Table 2. Age (years) in obtaining the best results for reaction time measures (ms) described by polynomial regression analysis

Variable	Age of best result	Best result (x_{min})	Parameter	
Visual reaction time	16.89	228.15	Regression equation	$y = 2.0256x^2 – 68.434x + 806.16$
			R^2 [%]	98.61
Auditory reaction time	16.83	197.12	Regression equation	$y = 1.7301x^2 – 58.242x + 687.29$
			R^2 [%]	99.18
Choice reaction time	15.69	287.61	Regression equation	$y = 6.4074x^2 – 201.13x + 1866$
			R^2 [%]	89.36

Table 3. Progression and rate of change of the reaction time measures

Variable	Parameter	Data from results						
		Age						
		7.30	8.30	9.30	10.30	11.30	14.20	19.58
Visual reaction time	RD%	100	86.40	78.91	75.64	69.66	57.39	57.07
	d%	–	–13.60	–7.49	–3.27	–5.98	–12.27	–0.32
Auditory reaction time	RD%	100	88.06	80.24	76.10	70.95	57.72	56.98
	d%	–	–11.94	–7.82	–4.14	–5.15	–13.23	–0.74
Choice reaction time	RD%	100	85.65	77.28	71.65	41.37	46.89	42.48
	d%	–	–14.36	–8.38	–5.64	–30.23	5.52	–4.41

RD% – rate of development for *n* age group compared with the results achieved at 7 years of age (%); d% = $RD\%_{n} – RD\%_{n-1}$, where $RD\%_{n}$ is the results of the *n* age group (%) and $RD\%_{n-1}$ is the results from the previous year (%)

and auditory reaction time (in relation to the results obtained at 7 years of age) was approximately 43%, whereas for choice reaction time this was 58%.

Discussion

This study measured simple and choice reaction time using a specially designed computerized test battery. The quality of the data obtained in this manner is dependent on the device itself and numerous external factors. These include the examiner administering the test, overall test conditions, time of day, participants' state including levels of fatigue, etc. All of the above may contribute to data variability and ultimately affect the accuracy and reliability of the results. In order to negate the influence of such external variables, the study was conducted by the same person, in the same room, on the same computer, and at the same time of day. Repeatability was verified by performing a pilot study by comparing test–retest results (obtained in two consecutive days), finding the test battery to have correlation coefficients ranging from 0.60 to 0.92. These values were similar to those obtained in other studies on coordination skills [13, 14].

Reaction time is determined by the type of stimulus presented to an individual. Our findings indicate a certain pattern in the arithmetic means of the measured reaction times. For all age groups, the group of females presented the best results for simple reaction time to an auditory stimulus, slightly worse results for reaction time to a visual stimulus, and the slowest times for reactions involving choice. These results are confirmed by data presented in other studies [4, 15]. It is hypothesized that this may be the result of the pathway of nerve impulse from the sensory stimulus and the brain. Neurophysiological studies have indicated that auditory stimuli reach the brain in approximately 8–10 ms whereas visual stimuli require 20–40 ms [4]. The difference between these reaction times is the same regardless of whether this involves a simple or choice reaction task [16]. The results of Kandel et al. [17] also affirm that the shortest reaction times are observed with auditory stimuli, believing this is caused by the faster processing of audio signals by auditory sensory receptors and the short transmission of afferent impulses to the brain.

One important factor that affects reaction time is age. The results of numerous comparative studies [4, 6, 9, 18] have indicated that reaction time is progressive until the age of approximately 20 years. Afterwards, reaction time performance begins to gradually deteriorate till 50–60 years of age [10], until the most deleterious changes of senescence take effect at approximately 70 years of age in both sexes [4, 9]. Our findings confirm these observations on the progressive nature of reaction time during early life. In all of the age groups under analysis, all types of reaction time improved (quickened) as a function of age. However, it needs to be mentioned that this developmental period includes very large variations in the rate of change of various coordination skills. Depending on the type of ability, a review of the literature (from Poland and around the world) finds that that improvements range from 20% to even 600% [19]. Nonetheless, it must be noted that many of the results were obtained through population-based research, which is known to have relatively low reliability.

In the present study, the best reaction times were recorded in females aged between approximately 16–17 years of age. These data are consistent with those reported in a longitudinal study by Hirtz [20], who also found that the the fastest reaction times were noted in 17-year-olds. In turn, Szopa et al. [21] indicated that the quickest reaction times to a visual stimulus were observed in girls aged 18–19 years in a population sample also from Kraków, Poland. For choice reaction time, Hirtz [3] reported that highest level was achieved at approximately the age of 16. Our own findings do not significantly differ from the results of these researchers, however, attention should be paid to the small intra-population variation at what age the best reaction time results may be achieved.

The results presented herein indicate that the greatest rate of change in reaction times to auditory and visual stimuli occurred between 7 and 8 years of age. A similar conclusion on the developmental dynamics during this period in human growth and development was also found by Mleczko in a group of Polish girls from the city of Kraków [12]. However, this discussion was limited to comparative data from longitudinal studies, as conclusions based on cross-sectional data (where each age group has its own internal structure) needs to be approached very carefully.

Analysis of intra-individual differences in coordination skills found that the results of approximately 20% of the population begin to plateau already during the developmental period. Moreover, in 10% of individuals, a deterioration of these skills was noted [3, 22]. Analysis of the above-cited references finds that while the development of coordination skills (including reaction time) during the developmental period is multi-directional, the largest gains are observed between 7 and 11–12 years of age.

Conclusions

On the basis of the results the following conclusions can be formulated:

1. The developmental period of simple reaction times to auditory and visual stimuli progresses until the age of 17, whereas for choice reaction time until 16 years of age. After this period, the results of the analyzed types of reaction times begin to plateau and stabilize.

2. Reaction time depends on the type of stimulus. The quickest time was in response to an auditory stimulus, then a visual stimulus, whereas the longest was in choice reaction time.

3. The most dynamic increase in the results of simple reaction times was between the age of 7 and 8 years, whereas for choice reaction time this was between 10 and 11 years of age.

4. One useful application of the presented results is in the recruitment and selection of athletes, as the role of reaction time as well as other motor coordination skills is important in determining player efficiency in the physical training process.

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