The ages of zone of proximal development for retrospective time assessment and anticipation of time event

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ABSTRACT
From childhood to adulthood, an individual’s ability to estimate and anticipate the timing of events changes continuously. This study investigated the ability of 287 children aged 5–14 years to estimate the duration of prior events and anticipate the timing of future events for determination of the age at which children improve their timing skills. The Luria neuropsychological assessment battery and the Wechsler Intelligence Scale for Children (WISC-IV) were applied to find correlations between timing skills and the development of cognitive functions. The findings demonstrated that retrospective estimation of duration has a zone of proximal development in children between the ages of six to eight; in these children, the accuracy of time assessment significantly improved after receiving the prompt. However, improvement in time estimation was significantly lower in those children who achieved lower results in the attention and memory tests and demonstrated reduced spatial and verbal reasoning skills. The zone of proximal development for the ability to anticipate the timing of future events was demonstrated in children between the ages of nine to eleven years. The improvement of time anticipation was negatively correlated with the number of mistakes made during the dynamic praxis test.

Introduction
It is generally known that the ability to conceive time is determined by multiple faculties including time estimation, subjective time awareness, and subjective time perspective (Lehmann, 1967). This ability is universal, with even infants demonstrating that they possess a sense of time, can note the temporal intervals between two events, and are aware of the duration of events (Boulton-Lewis, 1997; Brannon et al., 2004; Pouthas et al., 1993). However, the perception of objective time is socially dependent and must be internalized and mastered and therefore should develop throughout childhood (Block et al., 1999). The components of timing ability do not develop simultaneously. An initial and progressive increase in the quality of functions associated with time perception has been detected in children between the ages of three and ten years (Brannon et al., 2007). At this stage, children can accurately judge the lengths of temporal intervals when they had previously experienced the duration of various events repeatedly or had experienced the duration of daily activities (Friedman & Laycock, 1989; Rattat & Collié, 2020; Rattat & Tartas, 2017) and were able to name the seasons in which they occurred (Sharman et al., 2004). Adult-like knowledge of deictic status (like “yesterday” and “tomorrow”) and order appears between ages of four and six, but the knowledge of remoteness emerges after age seven (Tillman et al., 2017). This developmental transition from making implicit to explicit time judgments begins between the ages of three and six years (Lowe et al., 1983). By about the age of seven, children develop explicit time knowledge (Levin & Zakay, 1989). However, prior to the age of 10, most children do not spontaneously apply explicit time-related strategies (Pouthas et al., 1990). Furthermore, correct judgments concerning durations of time require sophisticated reasoning abilities that emerge at approximately eight years of age (Piaget, 1981) and accurate temporal judgments that develop before eight (e.g., Friedman & Laycock, 1989; Levin, 1992; Richie & Bickhard, 1988; Samartzis, 1992).

There is currently no consensus on the age at which children should be able to clearly demonstrate their ability to estimate time using specific units (seconds, minutes, hours, days, and years). Moreover, some studies have shown that the capacity to evaluate time using a clock, especially a blind clock, is culturally dependent (Kaplan, 2016). For example, there are units of time that are uncommon or even obsolete in European cultures but are widely used in other cultures or communities, such as the indiction cycle used by the Saros and Kalpa cultures (Meimaris, 1992). Nevertheless, knowledge regarding the various units of time is necessary for explicit time perception. This perception includes the estimation of a discrete length of time in order to compare it with a previously memorized standard. This requires the storage and retrieval of long-term memories and...
comparisons with other elements of working memory (Ciullo, 2016). The ability to estimate time therefore requires substantial cognitive resources, and it is thus dependent on an individual’s intelligence quotient (IQ), attention level, motivation, and other cognitive faculties. Finally, one of the most complicated processes involved in explicit time perception is the ability to anticipate the duration of upcoming events. The skill to plan the duration of a given activity develops during a child’s maturation phase and requires knowledge about units of time (seconds, minutes, days, weeks), the ability to recall the duration of previous events, discrimination between time intervals, and the ability to plan an activity.

At the same time, each culturally dependent or independent ability to perceive time has its own zone of proximal development. The zone of proximal development is defined as “the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers” (Vygotsky, 2004). The zone of proximal development (ZPD), created by Vygotsky, is a concept focused on maturing functions of consciousness and postulated that interaction between adult and child was the basis for learning. The concept introduced the ideal ages for the development of different mental functions (Allal & Ducrey, 2000; Hakkarainen & Brodsky, 2014; Shabani, 2010; Xi & Lantolf, 2021), when children, who were in the age specific for some cognitive function of ZPD and who received a hint, benefited from the communication and could reach their learning potential with the help of their teacher (Shabani, 2010; Wass & Golding, 2014). The hint (or positive interaction) that helps children to develop particular cognitive skills could vary and depending on the age and the task consisted in listening, observation, dialogue, hard-driving argumentation, metaphors or comparative analyses and etc. (Lee, 2012), could be intergroup or intimate (Roth & Radford, 2011). Regarding the development of explicit time perception, the most promising area for research is therefore the investigation of zones of proximal development, which is less dependent on a culturally-determined capacity to estimate time. It has been hypothesized that the ability to perceive time follows similar developmental stages as other cognitive functions; this is particularly true of the zone of proximal development (Bruner, 1984; Chaiklin, 2003).

The objective of the present study was to investigate the ability of preschool and school-aged children to assess and anticipate time intervals and to predict the durations of upcoming events. The study investigated the zone of proximal development (Berk & Winsler, 1995) for the capacity of children to estimate time intervals using hints (such as the duration of previous events). According to Vygotsky when a child is in the zone of proximal development for a particular task, providing the appropriate assistance will give him enough clues to achieve the task (Dixon-Krauss, 1996; Fani & Ghaemi, 2011; Vygotsky, 2004). To assist child to move through the zone of proximal development, researchers provided the information about correct time required to complete timing task successfully. At the same time, children of different ages have specific ZPDs regarding cognitive functions, in this point of view, we hypothesized, that supportive activities provided by the researcher could not facilitate an improvement of the child skills if he or she is not in the age of ZPD (Berk & Winsler, 1995; Copple & Bredekamp, 2009). An additional investigation was conducted to observe the association between the ability of children to estimate and anticipate the passage of time after being given a prompt and the development of cognitive functions required to complete the task.

**Methods**

**Participants**

Two hundred eighty-seven Russian children ages 5–14 years and 26 adults participated in our study. The participants had no history of brain injury or any psychiatric disorders. Descriptive statistics concerning the participants are presented in Table 1. The participants among children represented four age groups: 5–6 years (preschool), 7–9 years (primary school), 10–12 years (preteen) and 13–14 ages (teens). The 26 healthy adults ages 18–25 also participated in our study as a control group.

We used two types of age grouping: grouping by the developmental periods and grouping with one year steps. The latter grouping was used to detect the critical periods for zones of proximal development.

The participants were recruited from among the children who attend the Center for practical psychology “Equalize.” All data were collected between 2015 and 2018. Eight participants were excluded from the analysis due to data being missing from their test results. All children provided their verbal consent to participate in the study and were informed about their right to withdraw from the study at any time during the testing. A parent or guardian of each participant signed an informed consent form (the protocol in accordance with the Declaration of Helsinki) written in the participant’s native language prior to the tests being administered. The study was approved by the Ethics Committee of the Institute of Higher Nervous Activity and Neurophysiology of the Russian Academy of Science.

**Cognitive assessment**

Luria’s neuropsychological battery was applied for the assessment of cognitive functions such as visual and verbal memory, time perception, attention, visual-spatial perception, and executive function. The psychometric properties of neuropsychological assessment were repeatedly validated (Luria, 1970; Golden & Freshwater, 2001). Also, age standards were previously obtained for completing these tasks (Khomskaya, 2014; Luria, 1980; Plaisted et al., 1983).

The neuropsychological testing included:

1. Copying task: the image of a house with a fence and a tree were presented and the children were instructed to copy it. The number and type of errors (spatial errors,
the presence of superfluous and missing details) were evaluated. The task evaluates visual-spatial perception, and motor skills. The superfluous and missing details relate to executive function problems.

2. Quasi-spatial tasks: the first series of tasks included 6 pairs of objects of a barrel and a box with different co-positions (right, left, behind and etc.). The children were instructed to show a picture with objects in the correct position. The second series of tasks included verbally assigned tasks (6 tasks) for spatial or temporal relationships of objects. The number of correct answers was estimated. The test assesses the knowledge about spatial or temporal relationships between objects and understanding the complex logical and grammatical sentences related to spatial and temporal representations.

3. Attention tasks (Schulte tables, see paragraph “Assessment of time perception”). As attention test we used Schulte tables—square sheet of paper (20 x 20 cm), which was divided into 25 identical squares, each of which contains randomly arranged numbers from 1 to 25. According to the requirements, two adjacent digits should not appear in adjacent cells. Participants were instructed to search for all the numbers in order, to point and call numbers aloud. The speed of the task was estimated.

4. Visual memory tasks: included a set of five figures presented to children for 10–15 s with instruction to remember them, then the set was hidden and children were asked to draw the figures they remembered. If the children could not correctly recall all the figures, the procedure (with the same figures) was repeated again. The number of correctly reproduced figures after the first presentation, the number of presentations required for correct reproduction were evaluated.

5. Verbal memory tasks: included verbally assigned 5 words with instruction to remember them and then the children were asked to recall the words in the correct order. The number of correctly reproduced words after the first presentation, the number of presentations required for correct reproduction were evaluated.

6. Dynamic praxis: the neuropsychologist demonstrated the sequence of movements “palm-fist-rib” and (or) “fist-palm-rib” and then asked the children to repeat them. Both hands were examined. The number of repetitions for correct reproduction and type of errors (per-severations, simplification of the program, spatial errors, and stereotypes) were evaluated. The test assesses the executive functions, motor planning and inhibitory control.

7. The choice reaction. The children were instructed to raise their fingers in response to a neuropsychologist’s raised fist, and then raised a fist in response to a raised finger. First, the examiner showed a successive alternation of movements 3 times—“finger-fist” (creating a motor stereotype), after that the same movement was presented twice in a row, and then another. The number of repetitions necessary for mastering the task and

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**Table 1: Descriptive statistics (mean ± SD) of the groups’ characteristics (age, number of the subjects, gender, Wechsler test value Full-Scale IQ), “time reading”—real Schulte table’s reading time (in seconds)—,”time assessment”—subject’s assessment of the Schulte table’s reading time (in seconds).**

| Age       | n      | Schulte table’s reading time (in seconds) | Subject’s assessment of the Schulte table’s reading time (in seconds) |
|-----------|--------|------------------------------------------|---------------------------------------------------------------------|
| Preschoolers | 5      | 143.2 ± 14.3                             | 107 ± 8.3                                                          |
|            | 6      | 120.2 ± 15.3                             | 109 ± 10.1                                                         |
| Schoolers  | 7      | 110.2 ± 15.4                             | 109 ± 10.1                                                         |
|            | 9      | 109 ± 10.1                               | 110 ± 6.9                                                         |
| Preadolescents | 10   | 110 ± 10.1                               | 110 ± 10.1                                                         |
| Priests    | 12     | 110 ± 10.1                               | 111 ± 7.5                                                         |
| Eenters    | 13     | 110 ± 10.1                               | 111 ± 7.5                                                         |
| Teens      | 14     | 110 ± 10.1                               | 111 ± 7.5                                                         |
| Adults     | 16     | 110 ± 10.1                               | 111 ± 7.5                                                         |

F: Female; M: Male; IQ: Wechsler test value Full-Scale IQ.
the number of impulsive errors were evaluated. The test evaluates parameters such as impulsivity, executive functions, attentional control, and inhibitory control.

The Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) (Wechsler, 2003) was used to measure the intellectual ability of the participants (Table 1). Any participants who scored under 70 on the WISC-IV or had any symptoms of an autistic spectrum disorder or a history of mental or neurological diseases were excluded from the study. For further analysis we used only Full-Scale IQ score.

**Estimation of event duration**

Participants were instructed to locate the digits on a Schulte table (a 5x5 table displaying randomly distributed numbers was used) in ascending order and as quickly as possible. The participants were retroactively asked to estimate how much time had passed while they were completing the task (the time taken for the subject to complete the task was recorded by a researcher). After providing their estimations, the participants were told how long they had taken to complete the task. This acted as a prompt for the subject to estimate the time they would take to complete the next task. This procedure was then repeated a second time. The participants were again asked to locate digits on another Schulte table with the same complexity and to estimate how much time had passed while they were completing the task (Figure 1A).

**Anticipation of event duration**

Participants were instructed to complete a figure-contouring task. The offered task does not contain numbers and letters and can be performed by children from 5 years old (Akhutina et al., 2019). Prior to beginning the task, participants were asked to estimate how much time would be needed for the task to be completed. The participants then performed the task and the time taken for the task to be completed was recorded by researchers. After completing the task, participants were asked to estimate how much time had passed while they were contouring the picture. The participants were then told the actual length of time they took to complete the task. This procedure was then repeated a second time; participants were asked to contour another figure with the same complexity and were asked to anticipate the time they would take to complete the task (Figure 1B).

**Procedure**

All tests were administered by the author and a psychologist, trained in neuropsychological assessment, and were completed by individual participants working in a quiet and comfortable atmosphere. The assessments took approximately 90–120 min to complete and included a rest period, if required by the participant. The sequence of tests was varied pseudorandomly between participants. The randomization included the order of neuropsychological tests (quasi-spatial tasks, visual and verbal memory tasks, copying tasks, dynamic praxis, and the choice reaction task), tests to determine the assessment of time perception (Schulte tables and contouring tasks), the estimation of event duration tasks, and anticipation of event duration tasks. We conducted schemes in which the study blocks (neuropsychological testing (N), Estimation task (E), Anticipation task (A)) were pseudo-randomized: N-E-A, N-A-E, A-E-N, A-N-E, E-N-A, and E-A-N sequences were presented in the same ratio for each age group. Inside each block, the ratio of sequences was also equalized inside each age group. For example, during the estimation task, we presented in 50% cases Schulte Table 1 first, and Table 2 second, and in 50% cases—vice versa.
Parents of the participants were debriefed regarding the purpose of the study, and were offered the opportunity to discuss their children’s results with a qualified coinvestigator.

**Scoring**

The results of neuropsychological assessment were evaluated due to previously accepted protocols (Khomskaya, 2014; Luria, 1980; Mikadze et al., 2019).

The participants’ error of estimation event’s duration between the two series of Schulte tables’ reading and the error of anticipation of event’s duration between the two series of the contouring of figure task was analyzed. The participants’ error of estimation event’s duration was calculated for the two series of Schulte tables’ reading as modulus of the difference between estimated time and real-time. The error of anticipation of event’s duration was calculated for the two series of contouring task as modulus of the difference between anticipated time and real-time of completing the tasks.

The error of estimation of event’s duration after the first attempt allows to assess the level of development of the ability to estimate the event’s duration which child had unaided. Similarly, the error of anticipation of the event’s duration during the first attempt allows assessing the unaided time anticipation skills. The errors of anticipation and estimation in the second attempts indicate the ability to solve timing tasks with guidance. We assumed that a significant difference between errors of estimation (or anticipation) in the first and second attempts could be found only when the ability to estimate the event duration was in the ZPD. So, the age when the hint significantly improved the time estimation (anticipation) we called the age of ZPD for this function.

**Statistical analysis**

To determine the age when the capacity to assess and anticipate the time of event was in the zone of proximal development, the participants were divided into 11 groups (for each one-year period of age from 5 to 14 years old and adults). A 2-way repeated-measures ANOVA (Group 1 × attempt 2 (1st, 2nd)) was performed separately for each experimental block followed by Bonferroni correction and Post-hoc Bonferroni analysis; only significant post-correction effects were reported. The correlation analysis between neuropsychological testing and the results of time assessment and anticipation were performed using Spearman correlation analysis corrected for multiple comparisons by Bonferroni correction (the presented p values were adjusted) for five groups of children (preschoolers, primary schoolers, pre-teens, teens). Only significant effects and correlations were reported with the statistical power (1-β) ≥ 0.8.

**Results**

**Results of cognitive assessment**

The results of cognitive assessment were depicted in Tables 1 and 3. No significant differences were found between the four child groups in terms of the WISC-IV scores (Wechsler, 2003). There were no gender differences in time estimation and neuropsychological testing. Also, we did not find in our study any deviations from the normative samples in children during neuropsychological testing (including Schulte tables which were used for estimation of event duration).

**Correlations between neuropsychological testing age, and IQ**

Age was found to be negatively correlated with the duration of the Schulte task (Spearman rank correlations: r = −0.57, p < 0.001, see Table 1) and the number of missing details during the copying test (r = −0.51; p = 0.001), positively correlated with the number of correct answers during the verbal memory test (r = 0.44; p = 0.005), and the number of quasi-spatial tasks correct answers (r = 0.36, p = 0.02). The WISC-IV score negatively correlated with attempts required for successful dynamic praxis (r = −0.37, p = 0.016). The correlation matrix presented in Table S1.

**Estimation of event duration**

Most participants overestimated the time they spent reading the Schulte table. The overestimation was negatively correlated with age (r = −0.68, p = 0.0001). Compared to children aged nine and older (who accurately estimated event durations), children aged five to eight significantly overestimated the time taken for task completion during their first attempt (Figure 2). After the hint was given, time estimations became significantly more accurate for children aged...
six to eight and the error associated with the time assessment decreased significantly \(F(10, 302) = 29.577, p < 0.001, \text{power} = 1.0\). The results therefore indicate that children between the ages of six to eight years of age begin to use the prompt effectively.

**Anticipation of event duration**

All participants overestimated the duration of both the upcoming event and the past event. Additionally, significant differences were found in the anticipation of event time duration between groups (Figure 3). Older children demonstrated a lower error in anticipating the duration of events \(r = -0.58, p = 0.008\). Compared to other age groups, children ages 9–11 significantly improved their accuracy of time anticipation after being given the prompt \(F(10, 302) = 5.840, p < 0.001, \text{power} = 0.98\) (Figure 3). The amount of error in anticipating an event’s duration in the first attempt was highest in children of five, decreased with increasing age and reached a plateau at the age of 12; no significant differences in results were detected between participants over 12 years old and adults. On the second attempt, the error plateau was reached at age 10 (see Table 2).

Like adults, children between the ages of 12–14 were best able to estimate the duration of the contouring task. Accuracy of time assessment for the contouring task between the first and second attempts (differences between estimation of contouring time and real time of contouring were recorded) were only observed to differ in children age 12; participants in this group significantly improved their assessment of time duration during the second attempt \(F(10, 302) = 21.976, p < 0.001, \text{power} = 1.0\).

**Correlation between the estimation of an event’s duration and the results of cognitive tests**

The error of time assessment was inversely correlated with age \(r = -0.42, p = 0.009\), the results of the visual memory test (the number of correctly recalled figures; \(r = -0.64, p < 0.001\), and positively correlated with the time spent reading the Schulte table \(r = 0.59, p < 0.001\). It was

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**Figure 3.** The difference between anticipation and real time of contouring (anticipation of time—real time). Solid line—first try, dotted line—second attempt. Stars—significant differences between two probes \(p \leq 0.05\). The vertical axis—time in seconds, the horizontal axis—age (years).

**Table 2.** The results of the task “Anticipation of the event’s duration” before and after the prompt (in seconds—s).

| Age | Anticipation of time | Real time | Time assessment | Anticipation of time | Real time | Time assessment |
|-----|----------------------|-----------|-----------------|----------------------|-----------|-----------------|
|     | Before prompt        |           |                 | After prompt         |           |                 |
| Preschoolers | 5 | 826.3 ± 91.8 | 128.2 ± 25.1 | 815.9 ± 34.5 | 819.4 ± 37.1 | 106.7 ± 15.1 | 812.5 ± 31.4 |
|       | 6 | 803.5 ± 85.7 | 118.7 ± 25.4 | 577.3 ± 25.6 | 801.7 ± 28.5 | 119.4 ± 12.4 | 576.9 ± 26.9 |
| Schoolers | 7 | 656.2 ± 87.2 | 119.2 ± 21.2 | 441.0 ± 31.2 | 614.9 ± 27.5 | 133.7 ± 15.5 | 423.2 ± 37.8 |
|       | 8 | 605.3 ± 89.7 | 112.1 ± 14.5 | 310.8 ± 27.5 | 578.6 ± 29.7 | 113.2 ± 14.9 | 349.1 ± 26.9 |
|       | 9 | 2247 ± 41.4 | 124.3 ± 19.4 | 195.1 ± 20.2 | 217.5 ± 21.5 | 126.1 ± 19.8 | 201.5 ± 27.7 |
| Preteens | 10 | 219.2 ± 42.1 | 84.2 ± 9.6 | 141.2 ± 16.6 | 163.2 ± 24.9 | 91.4 ± 11.1 | 136.4 ± 17.7 |
|       | 11 | 205.1 ± 39.4 | 81.5 ± 12.0 | 149.1 ± 17.8 | 172.1 ± 23.2 | 88.7 ± 11.1 | 157.6 ± 12.6 |
|       | 12 | 175 ± 35.9 | 83.5 ± 11.7 | 115.2 ± 12.8 | 103.8 ± 19.3 | 84.9 ± 13.3 | 85.8 ± 14.4 |
| Teens | 13 | 121.7 ± 42.4 | 75.6 ± 8.8 | 104.6 ± 12.1 | 104.8 ± 16.1 | 80.2 ± 10.7 | 94.9 ± 9.5 |
|       | 14 | 117.7 ± 23.1 | 75.6 ± 4.9 | 99.3 ± 10.2 | 100.4 ± 15.7 | 80.4 ± 9.5 | 91.7 ± 7.8 |
| Adults | 15 | 98.25 ± 22.5 | 62.1 ± 3.4 | 64.1 ± 4.9 | 85.4 ± 12.8 | 68.8 ± 5.1 | 71.6 ± 5.0 |

**Table 3.** The descriptive statistics of results of Luria’s neuropsychological battery.

|              | Preschoolers | Schoolers | Preteens | Teens | Adults |
|--------------|--------------|-----------|----------|-------|--------|
| Quasi-spatial tasks correct answers | 4.9 ± 0.8 | 5.2 ± 0.9 | 5.5 ± 1.0 | 5.7 ± 0.7 | 5.9 ± 0.8 |
| Visual memory tasks attempts | 0.7 ± 1.8 | 0.4 ± 1.8 | 0.4 ± 1.3 | 0.2 ± 0.9 | 0.2 ± 0.7 |
| Visual memory tasks correct | 3.3 ± 1.8 | 2.4 ± 2.1 | 3.6 ± 2.2 | 4.1 ± 1.7 | 4.2 ± 1.5 |
| Auditory memory tasks attempts | 0.8 ± 2.1 | 0.6 ± 2.2 | 0.5 ± 1.9 | 0.4 ± 1.6 | 0.4 ± 1.7 |
| Auditory memory tasks correct | 3.5 ± 1.5 | 4.1 ± 2.6 | 4.2 ± 1.7 | 4.6 ± 1.0 | 4.8 ± 0.7 |
| Copying task mistakes | 0.9 ± 1.3 | 0.7 ± 0.9 | 0.8 ± 1.9 | 0.5 ± 1.6 | 0.3 ± 1.1 |
| Dynamic praxis attempts | 0.8 ± 2.3 | 0.8 ± 1.6 | 0.5 ± 1.3 | 0.2 ± 1.7 | 0.2 ± 0.8 |
| Dynamic praxis mistakes | 1.2 ± 1.2 | 1.1 ± 0.9 | 0.8 ± 1.8 | 0.4 ± 1.5 | 0.2 ± 1.1 |
| Choice reaction attempts | 0.9 ± 2.0 | 0.7 ± 1.7 | 0.4 ± 2.1 | 0.4 ± 0.6 | 0.3 ± 0.9 |
| Choice reaction mistakes | 0.8 ± 1.3 | 0.7 ± 1.9 | 0.6 ± 1.8 | 0.5 ± 1.7 | 0.3 ± 1.3 |
positively correlated with the number of trials required for correct reproduction during verbal memory tests ($r = 0.36$, $p = 0.04$) and visual tests ($r = 0.39$, $p = 0.02$), and the number of missing details in the copying task ($r = 0.48$, $p = 0.005$). The error of the time assessment was also negatively correlated with the number of correct answers during the quasi-spatial solving task ($r = -0.46$, $p = 0.006$). More specifically, the greater the error of the time assessment task, the higher the number of spatial and quasi-spatial verbal mistakes. The error made during the time anticipation task was found to be positively correlated with the number of mistakes made during the dynamic praxis task ($r = 0.8$, $p < 0.001$). The correlation matrix presented in Table S2.

**Discussion**

These findings support the hypothesis that a child’s concept of time and their ability to estimate the duration of events and plan for future events develops during maturation (Piaget, 1981; Smythe & Goldstone, 1957). Additionally, each category of time perception is observed to have its own zone of proximal development (Sargent, 2014). More particularly, the zone of proximal development for the ability to assess an event’s duration was about age seven; for the capacity to anticipate an event’s duration, the zone of proximal development was observed between ages nine to eleven, as after prompting, the event’s duration estimation and anticipation became more accurate. These skills are therefore actively developing during these ages and children are sensitive to information on time perception skills at this stage. Children from ages five to eight overestimated the time of completion for the Schulte table reading task; however, unlike 5-year-old children, children ages six to eight were able to improve their inaccurate estimation after receiving a prompt. Nine-year-old children displayed similar accuracy in time assessment as adults; receiving a prompt did not substantially improve their estimations. However, the accuracy of time assessment of the contouring task was not improved by the prompt until age 12.

These findings may be explained by the complexity of the contouring task, which, in contrast to the Schulte table reading task, was not followed by a demonstration of numerical skill. As shown by Labrell et al. (2016), the capacity to estimate time significantly increases between the ages of six and eight and is closely associated with an individual’s numerical skills. At age six, children can apply their counting skills for the estimation of the duration of the Schulte test by aligning the prompt with the consecutive numbers of Schulte tables; the time duration prompt can help children relate the speed of number tracking with the passage of time. These findings also supported the observation that the ages of six to eight are a zone of proximal development for the estimation of an event’s duration. In the contouring task, no numerical sequences were provided as external indicators to the passage of time and children therefore had to use their own internal time units, which continue to develop throughout adolescence.

The present study revealed that a child’s ability to improve their accuracy in time estimation using the prompt was correlated with the development of attention and memory skills. Moreover, improvements in time assessment skills were found to be more pronounced in participants who made fewer spatial and quasi-spatial verbal mistakes. Such data supports previous findings that explicit time perception skills depend on the general level of an individual’s cognitive capacities (Droit-Volet & Zélanti, 2013b). These findings are also supported by other studies that have reported an inverse relationship between the brain’s processing speed and an individual’s perceived passage of time (Goddard, 2000). At the same time, the development of the ability to judge the passage of time was closely related to the development of spatial cognition (Coull & Droit-Volet, 2018), which was associated with the maturation of the temporal, parietal, and frontal regions of the brain (Nagy, 2004). The zone of proximal development for the ability to estimate the duration of an event was based on the cognitive functions of maturation. The relationship between the accuracy of an individual’s perception of time and that individual’s attention level has also been previously observed. Several researchers have demonstrated that in young children (from three to eight), the demonstration of poor judgment during the completion of classical Piagetian tasks in which children had to compare the durations of two synchronous movements is not due to their inability to correctly judge time, but rather to their limited capacity to demonstrate their ability to focus their attention (Droit-Volet, 2006). The reported association between difficulties assessing the passage of time and mistakes in attention and memory tests was also consistent with symptoms of a distorted sense of time in subjects with Attention-Deficit Hyperactivity Disorder (ADHD) (Goddard, 2000). Children and adolescents with ADHD display impairments both in terms of their ability to discern duration and the precision with which they reproduce the intervals during the estimation task (Barkley, 2001; Toplak, 2003; Toplak & Tannock, 2005).

The ability to predict the duration of an event was found to be associated with the development of executive functions and planning skills. This finding corresponded to previous observations that showed that children between the ages of six and ten years were characterized by an intensive development of proactive control which is engaged in anticipation of future events. This allowed children to anticipate and prepare for upcoming events and required high-performing working memory (Chevalier, 2014). Children under the age of eight mainly used reactive control, which was only activated when the event had already occurred; children displayed difficulty in planning the upcoming event (Pani, 2013). By age eight, children can demonstrate both types of control, depending on what is required by the situation. However, starting from age 10, children demonstrate a preference for using proactive control, where possible (Chevalier et al., 2015). Demonstrating the proactive control required for the anticipation of an event’s duration is provided by a wide neural network which includes the prefrontal cortex (Zandbelt et al., 2013). The prefrontal cortex is known to
continue maturing during childhood and reaches a peak in cortical thickness by age 11. In the present study, mistakes observed during the dynamic praxis tests were correlated with errors in time anticipation; errors in time anticipation can therefore be associated with the development of proactive control. In general, it can be hypothesized that the development of proactive control, and other higher cognitive functions associated with the activity of the prefrontal cortex, contribute to the zone of proximal development for the ability of individuals to anticipate the duration of an event (Chevalier et al., 2013).

Finally, the findings of the present study concern the dependence of children’s timing ability on both the difficulty of the task and their level of cognitive development. Numerous studies have shown that an individual’s time sensibility reaches an adult-like level at about ages eight to nine, although, regarding more difficult tasks, differences in time judgment between children and adults may persist until adolescence (Droit-Volet & Zélanti, 2013a; Zélanti & Droit-Volet, 2011). A similar trend regarding the development of time perception was observed in the present study. More specifically, it was found that the ability to estimate previously anticipated time durations influenced the perceived complexity of the task for school-aged children and preteens and led to the convergence of estimation and anticipation time. Moreover, 7- and 8-year-old children demonstrated the deterioration of time estimation that was associated with deficits in executive control function.

Development of the ability to time events—especially regarding explicit time perception—therefore stems from multiple factors, including the experience of the temporal regularities of events, the awareness of the passage of time, and the development of general cognitive capacities (Droit-Volet, 2016; Droit-Volet & Zélanti, 2013b). Moreover, many neuropsychological indicators were found to influence a child’s ability to time events, regardless of the child’s age. In particular, observed accuracy in the assessment of time was found to be significantly lower among those children who displayed lower results in the attention and memory tests. Therefore, the awareness of time appears to depend on a child’s attention and short-term memory capacities, which are related to the maturation of both the prefrontal cortex and the hippocampus (Wittmann, 2007). Previous findings also demonstrated that preschoolers had difficulty perceiving explicit and abstract representations of time. This ability to judge the duration of events improves as cognitive and executive functions develop with the maturation of the prefrontal cortex (Coull & Droit-Volet, 2018).

**Conclusions**

Our findings demonstrate that the timing abilities of children aged 5–14 were related to the general development of their cognitive functions. The estimation of time task during the Schulte table reading demonstrated a zone of proximal development in 6- to 8-year-olds. The zone of proximal development for the ability to anticipate or predict the duration of an event was observed in children aged nine to eleven. Additionally, the accuracy of the assessment of time was significantly lower in those children who achieved lower results on the attention and memory tests. The improvement of the assessment of time during Schulte table readings correlated with enhanced capacities for spatial and verbal reasoning skills. Finally, the accuracy of the anticipation of the timing of future events was correlated with higher performance on tests for inhibitory control.

**Limitations**

The study investigated the ages of zones of proximal development for timing tasks in Russian children and there are therefore potential limitations in extrapolating this data to other populations. Furthermore, this study used a limited number of neuropsychological tests—which were selected according to the study hypothesis—and may have affected the determination of children’s cognitive abilities. Also, there might be effects that were not found in this study because of limited statistical power, which should be explored in future studies.

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