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School-age children can form time-based event expectancy for context-atypical foreperiods

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ABSTRACT

Using a binary choice response task, we compared the formation of time-based event expectancy and its underlying mechanisms between 30 children aged 8–12 and 39 young adults aged 18–35. During a learning phase, two different foreperiods (FPs) predicted the response target's left or right location with a probability of .8, inducing time-based expectancy. We found that time-based expectancy was developed in school-aged children. However, children showed a significant expectancy effect, especially for context-atypical FPs. In a following test phase, the pairs of FPs changed from shorter to longer, or from longer to shorter, and the target's location was no longer predictable on the basis of FP duration. Children did not transfer their expectancy from the learning phase to the test phase, suggesting that children, in contrast to adults, do not uniformly employ relative representations of time in time-based expectancy.

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Children; timing; associative learning; time-based expectations; attentional control

Introduction

The developmental literature shows that some cognitive functions are not fully developed in children, and that different cognitive functions have different developmental time courses. For example, the maturation of executive functions and working memory extends into young adulthood (Blakemore & Choudhury, 2006), while attention skills improve with increasing age during childhood (Dye & Bavelier, 2010; Plude et al., 1994; Trick & Enns, 1998). Perceptual sensitivity to time has also been shown to improve during childhood (Droit-Volet, 2013), and might be linked to the development of other cognitive functions (Johnson et al., 2015) such as working memory, general information processing (Droit-Volet & Zélanti, 2013) and attention capacities (Gautier & Droit-Volet, 2002). Interestingly, Droit-Volet et al. (2016), by comparing explicit and implicit timing ability in adults and children of different ages, showed that processing of time is independent of age in the implicit task but explicit timing ability improves with age due to developmental improvement of executive control function.

Also for the expectancy of intervals, previous studies have gathered evidence concerning the developmental time course. Expectancy for intervals is typically investigated with the so-called variable foreperiod (FP) paradigm (Langner et al., 2010; Steinborn & Langner, 2011). A FP is an interval between a warning signal and an imperative stimulus. When the FP randomly varies from trial to trial, participants tend to respond faster for longer FPs (Steinborn et al., 2017). Performance in such variable FP paradigms also varies sequentially: reaction times increase with FP duration on trial *n*−1 (Steinborn & Langner, 2012; Steinborn et al., 2008, 2010).

Developmental studies have shown that these sequential effects are already present in 4- to 5-year-old children, but the so-called variable FP effect (i.e. reaction times decrease as a function of FP on trial *n*) appears gradually only some years later (Vallesi & Shallice, 2007). Recently, Johnson et al. (2015) employed a temporal attention task to study the ability of children to use information cues to voluntarily orient their attention to a certain point in time at which an event will occur.

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They found that children (mean age 11 years) were unable to use temporal information cues to speed up responses, but were able to implicitly use the temporally predictive information inherent in the passing of time to improve response times (RT) (Johnson et al., 2015). Johnson et al (2015) used a paradigm with lateralised target stimuli in which the temporally predictable targets were not spatially predictable. Specifically, they used symbolic stimuli, such as different parts of a clock-face as cues, in which short and long lines represented short or long temporal intervals. The cues were presented very briefly (100 ms) prior to empty FPs. Thus, the cues in themselves might have been more difficult to discriminate for children relative to adults (Johnson et al., 2015; Mento & Tarantino, 2015). More recently, Johnson et al. (2016) presented duration-based temporal cues several times in an isochronous sequence and found that school-aged children were able to use such cues to make predictions of the time of target onset. Contrary to the study by Johnson et al. (2015), Mento and Tarantino (2015) used a central target stimulus to study the ability to generate temporal prediction in school-age children (from 6 to 11 years). They did not manipulate the cue's validity, but compared performance between temporal cueing and neutral cueing blocks. In temporal cueing blocks, they used coloured blue and orange visual cues, while one of the colours predicted a short FP (600 ms) and the other one a long FP (1400 ms) duration. In the neutral cueing blocks, the visual cue was black for both short and long SOA durations. They found that children responded faster to target in temporal cueing when compared with neutral cueing blocks, suggesting that school-age children were able to improve their performance by using information provided by external discrete temporal cues (Mento & Tarantino, 2015). In addition, Mento and Vallesib (2016) showed that the neural correlates underlying temporal orienting were already established in 8–12 years old children. A recent study by Mento et al. (2018) found that temporal attention in 8- to 12-year-old children operates by exploiting oscillatory mechanism. Although prior studies suggested that school-aged children are able to selectively allocate attention in time, little is known about their ability to form timed-based event expectancy.

In time-based event expectancy, contrary to studies on expectancy of intervals, which is independent of the expected event identity, participants do not expect the upcoming intervals, but they expect upcoming events implicitly based on the duration of waiting time (Kunchulia & Thomaschke, 2016; Thomaschke et al., 2015; Thomaschke & Haering, 2014). In other words, participants do not expect a temporal interval as such, but they expect an event based on the duration of the preceding interval (Thomaschke & Haering, 2014).

This aspect of human temporal control is essential for interacting with the environment in a temporally adapted manner. The research on temporal orienting reviewed above deals with the ability to schedule the system's general processing capacity to a certain point in time. This is important in situations where one can expect that in, for example, 2 s happens something important, but one does not exactly know what it will be.

Time-based expectancy, on the contrary, allows us to bias the cognitive system specifically in a certain direction based on the flow of time. This is of advantage in situation where one can expect one particular processing requirement at an earlier point in time, but another one at a later point in time. Such regularities are pertinent in many common interaction scenarios (c.f. Aufschnaiter et al., 2018; Aufschnaiter et al., 2018; Shahar et al., 2012; Thomaschke & Haering, 2014) such as, for example, joint actions (Vesper et al., 2017), and verbal communication, where the duration of inter-turn silence predicts the valence of the communication partner's response (Roberts & Francis, 2013; Roberts et al., 2011; Roberts & Norris, 2016).

Thus, with fully developed temporal orienting skills, but without any time-based expectancy ability, individuals would be unable to exploit an essential aspect of temporal regularities in the environment. Consequently, investigating the developmental time course of time-based expectancy seems to be at least equally important as exploring the development of temporal orienting abilities.

This aspect of human temporal cognition is typically investigated with a certain variant of the FP paradigm, where the duration of the FP predicts, with a certain probability, the current trial's target. This design is commonly referred to a time-event correlation paradigm (Thomaschke & Dreisbach, 2015).

Here, we investigated time-based event expectancy in school-aged children. That is we tested whether children can employ temporal duration as cue to response targets. Since previous studies by

Mento and Vallesib (2016) showed that temporal orienting ability and its underlining neural mechanisms has been already developed in children at least from 8 to 12 years of age, in the present study, we focused on the same age range of children (i.e. 8–12 years). To create a child-friendly experimental procedure, we applied a gamification strategy. We employed a time-event correlation paradigm, realised as a basic computer game, in which target's two possible locations (left and right) and two possible FPs appear overall equally often. But one of the target's locations was paired with a short FP and the other with a long FP, in 80% of the trials. In this paradigm, the formation of time-based event expectancy is evidenced by faster responses to frequent FP – target's location combinations, compared with infrequent ones (Kunchulia & Thomaschke, 2016; Thomaschke et al., 2011, 2015).

A previous study with adult participants (Thomaschke et al., 2015) suggested that time-based expectancy operates on relative (rather than absolute) representations of time. That means we associate response targets with, for example, the shorter one of two possible intervals, instead of associating them with, for example, 500 ms. In that study, after the formation of time-based event expectations in a learning phase, in a test phase, a new duration range with FPs that were either considerably shortened or considerably lengthened was employed. Participants transferred their time-based expectancies according to the relative duration of FPs (e.g. the shorter one of the current pair), rather than to the absolute duration of FPs (e.g. 500 ms; Thomaschke et al., 2015). Using a modified version of the same paradigm(Thomaschke et al., 2015), it has been also showed that the ability to form time-based event expectancies was reduced for older participants (aged 60–75) compared with younger adults (aged 20–32) (Kunchulia et al., 2019). Interestingly, recent studies using the same gamification strategy found that children with Autism Spectrum disorder (aged 6–13) showed significantly greater sensitivity towards time-based predictability than same-aged typically developing children (Kunchulia et al., 2017; Kunchulia et al., 2020). These findings indicate that using a paradigm with gamification strategy (Thomaschke et al., 2015) is a good tool to assess age-related changes and developmental differences in timed-based expectancies.

In the present study, by comparing performance between children from age 8–12 with adults from age 18–35, we aim to determine first, to which extent school-aged children can form time-based event expectations; following previous studies on other implicit timing capacities (Droit-Volet et al., 2016; Mento & Tarantino, 2015; Mento & Vallesib, 2016), we hypothesise that children can form time-based expectancy, but to a lesser extent than adults. Second, we aim at establishing whether children, like adults, employ relative representations of time intervals when forming time-based event expectations. Yet, previous studies provide no clear hypothesis about the time representation (absolute vs. relative) employed by children in time-based expectancy. Thus in the current study, we test both hypotheses.

Experiment 1

The aim of Experiment 1 was to study the formation and the temporal representational mode of time-based event expectancy in school-aged children. Participants adapted to a shorter pairs of FPs (200 and 800 ms) and FPs predicted target's locations combinations with a probability of 80%. Then the pair of FPs changed from shorter (200 and 800 ms) to longer (800 and 1400 ms) and FP–target's location correlation became neutral (50%).

Method

Participants

Right-handed, healthy participants from two age groups took part in the experiment: children aged 8–11 years ($n = 14$, 7 male, mean age = 9.64, SD = 1.08 years), and adults aged 20–35 ($n = 19$, 7 male, mean age = 24.6, SD = 4.5 years). Three children were 8 years old, two were 9 years old, six were 10 years old and three were 11 years old. The study was approved by the local Ethics Committee, and the experiments were carried out in accordance with the World Medical Association Helsinki Declaration. Verbal informed consent was obtained for all participants, while written informed consent was obtained from the parents of all children and from all adult participants.

Apparatus

We used E-Prime2 for running the experiment and collecting data (Schneider et al., 2002). Data were collected on a Windows PC with LCD display (screen resolution 1280 × 800 pixels). Responses were collected using a standard optical mouse.

Procedure

The procedure was similar to a previously used one by Kunchulia and Thomaschke (2016). We tested participants individually in a quiet room. They performed a binary choice response task, mimicking a basic computer game. In this game-like paradigm, participants operated a donkey character to chase a moving carrot, which moved repeatedly from the bottom to the top of the screen diagonally upwards left, or diagonally upwards right. The carrot moved until it would finally be caught by the donkey character at a fence at the upper border of the screen (see Figure 1). Participants had to press the left mouse button to make the donkey follow the carrot to the left and to press the right mouse button to move the donkey to the right.

Pressing the mouse button made the donkey jump on the carrot, but the carrot jumped away again, after a short or long response– stimulus interval (i.e. from mouse click to carrot movement). This response– stimulus interval represented the FP. If participants pressed the wrong key or pressed the key before the carrot had jumped the game was paused for three seconds and a tone was played as an error message (see, Kunchulia & Thomaschke, 2016; Szameitat et al., 2009; Thomaschke et al., 2015). We used a short (200 ms), a medium (800 ms) and a long (1400 ms) FPs.

The learning phase consisted of four blocks with 120 valid and 30 invalid trials in each block (600 trials in total). In the valid trials, short or medium FP duration validly predicted the carrot's next movement direction with a probability of .8. For half of the participants, medium FPs predicted the carrot's movement to the left and short FPs predicted a movement to the right; for the other half, this association was inverted. In the invalid trials, the carrot's next movement direction was opposite to the direction predicted by the association learnt in valid trials. These invalid trials occurred with a probability of $p = .2$. We expected, if participants

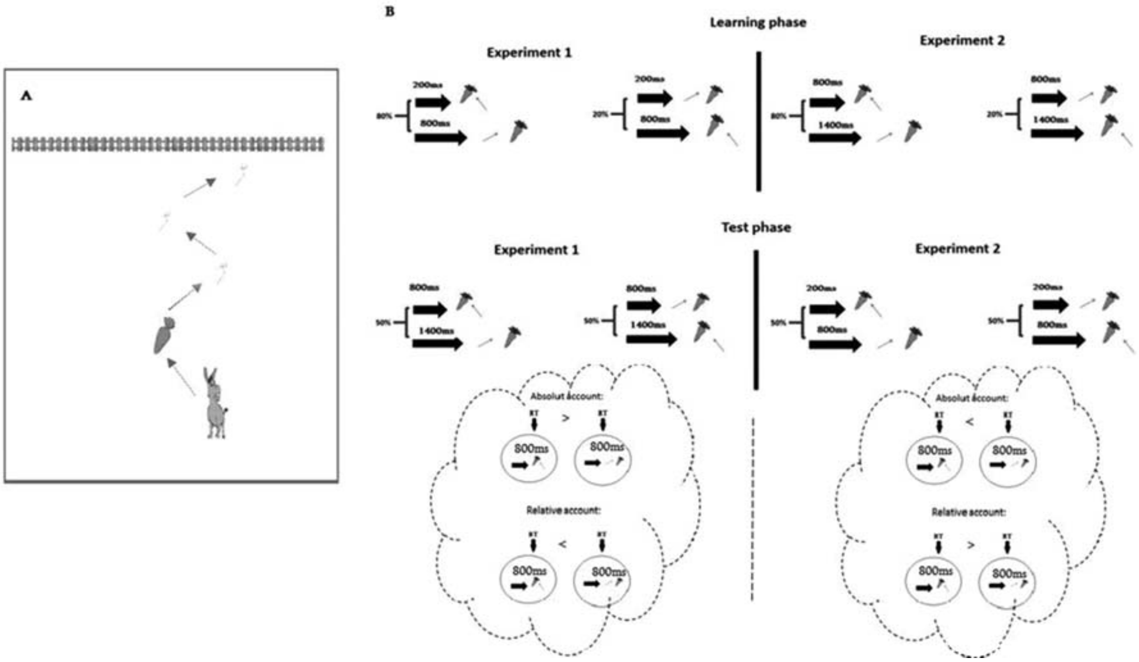

Figure 1. Experimental task. (A) Schematic illustration of the layout of the choice response task. The donkey starts chasing the carrot at the bottom of the screen and 'captures' it at the fence. (B) The layout of experimental procedure. In Experiment 1, participants adapted to 200 and 800 ms FPs with a probability of 80%. In the test phase, 1400 and 800 ms FPs were displayed with a probability of 50%. In Experiment 2, participants adapted to 800 and 1400 ms FPs with a probability of 80%. In the test phase, 200 and 800 ms FPs were displayed with a probability of 50%. When RTs are shorter for the event that was frequently paired with that FP in the practice phase, the absolute model is supported. The relative model would, on the contrary, predict that RTs are shorter to the target which was frequently paired with the (now suspended) short or long FP in the practice phase, because the FP currently under scrutiny is, now the relatively shorter or longer one of a pair of FPs.

form time-based expectancies in this phase, they would respond faster and more correctly to valid trials than to invalid ones.

In a following test phase (5th block, 150 trials), the short FP was replaced by a longer one, but the medium FP appeared again. However, the carrot's next movement direction was no longer predictable ($p = .5$) on the basis on FP duration. Here, we expected that previously acquired expectancies would be transferred from the learning phase to the test phase. If participants formed time-based expectancy according to *absolute* time, they should respond faster to the medium FP in the test phase with the response which was frequent after that the medium FP in the learning phase. If, on the contrary, participants formed time-based expectancy according to *relative* time, they should respond faster to the medium FP in the test phase with the response which was frequent after the *short* FP in the learning phase, because the medium FP is in the present context the relatively shorter one (Kunchulia & Thomaschke, 2016). Note, that participants do typically not recognise such manipulated regularities (Thomaschke et al., 2015), though we did not explicitly verified this in the present study.

Data analyses

The mean RT from the test phase and the last block of the learning phase were analysed using a mixed analysis of variance (ANOVA) with the between-subjects factor of Age Group (adults vs. children) and the within-subjects factors of Foreperiod (relative duration: short vs. long) and Validity (Valid, Invalid).

The screening procedure was the same as that used in our previous studies with this paradigm (see, e.g. Kunchulia & Thomaschke, 2016). Error trials and trials with RT deviating from the condition mean by more than three standard deviations were excluded from the RT analysis (Bush et al., 1993). In total, 2.1% of all trials were excluded from the test phase, and 2.18% of all trials from the last block of the learning phase.

Results

Formation of time-based expectancy: learning phase

In the learning phase, an ANOVA of the mean RT showed main effects for the within-subjects factors Validity, $F(1,31) = 11.61$, $p = .002$, $\eta^2 = 0.272$, and Foreperiod, $F(1,31) = 23.57$, $p < .001$, $\eta^2 = 0.432$. There also was a significant three-way interaction between Age Group, Foreperiod and Validity, $F(1,31) = 4.45$, $p = .043$, $\eta^2 = 0.126$. However, interaction between Age Group and Validity was not significant, $F(1,31) = 1.01$, $p = .323$, $\eta^2 = 0.032$. There also was no significant interaction between Age Group and Foreperiod, $F(1,31) = .52$, $p = .47$, $\eta^2 = 0.017$.

Separate ANOVA for both groups showed significant main effect of Foreperiod for children, $F(1,13) = 9.34$, $p = .009$, $\eta^2 = 0.415$, and for adults, $F(1,18) = 15.11$, $p = .001$, $\eta^2 = 0.456$. There was a significant main effect of Validity for children, $F(1,13) = 5.66$, $p = .033$, $\eta^2 = 0.303$, and for the adults group, $F(1,18) = 5.28$, $p = .034$, $\eta^2 = 0.227$.

In order to further resolve the three-way interaction, we analysed the Validity effects for the short FP and the medium FP in both groups separately. In the children group, there was a significant effect for the short FP, $t(13) = 2.72$, $p = .041$, Cohen's $d = 0.6$, which was due to the fact that the children responded faster at the valid trials than to invalid trials following the short FP. This means that children showed an expectancy effect at the short FP. There was no such effect in the adults group at the short FP, $t(18) = .74$, $p = .46$, Cohen's $d = 0.17$.

However, there was a significant effect at the medium FP for adults, $t(18) = 2.13$, $p = .047$, Cohen's $d = 0.49$, but not for the children, $t(13) = .253$, $p = .8$, Cohen's $d = 0.07$ (see Figure 2).

Transfer of time-based expectancy: test phase

In the test phase, we conducted a mixed ANOVA with the between-subjects factor Age Group (children vs. adults) and the within-subjects factors Foreperiod (medium vs. long) and Validity (valid vs. invalid). Note that Validity refers to whether the current FP– event combination was frequent in the learning phase. In the test phase itself, each combination was equally frequent (see the Methods section). Note further, that the factor Validity is coded according to *relative* time representation (i.e. 'frequent' is the combination of 800 ms with the event that had been frequent at 200 ms previously, and the combination of 1400 ms with the target that had been frequent at 800 ms previously).

In the test phase, the ANOVA of the RT showed a significant main effect for Foreperiod, $F(1,31) = 16.55$, $p < .001$, $\eta^2 = 0.368$, due to both adults, $F(1,18) = 4.86$, $p = .\ 041$, $\eta^2 = 0.212$, and children, F

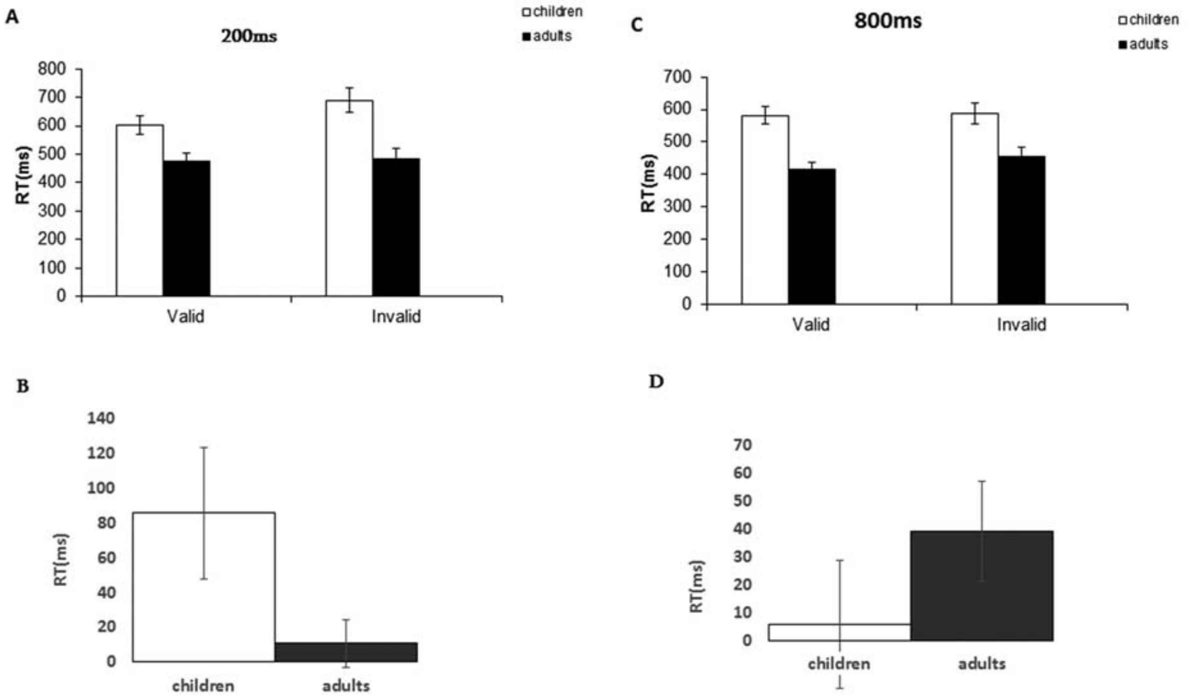

Figure 2. The learning phase (Block 4). (A) The mean RTs at the short (200 ms) FP. (B) Magnitude of the Validity effect at the short (200 ms) FP. (C) The mean RTs at the medium (800 ms) FP. (D) Magnitude of the Validity effect at the medium (800 ms) FP. Error bars represent the standard error of the mean.

$(1,13) = 11.32$, $p = 0.\ 005$, $\eta^2 = 0.466$, responded faster at the long than medium FP.

There was a marginal significant trend of Validity, $F(1,18) = 3.19$, $p = .09$, $\eta^2 = 0.151$, for adults, but not for children, $F(1,13) = .18$, $p = .67$, $\eta^2 = 0.14$. Follow-up *t*-tests for individual FPs showed a main Validity effect at the long FP for adults, $t(18) = 2.286$, $p = .035$, Cohen's $d = 0.52$ but not for the medium FP, $t(18) = 0.466$, $p = .647$, Cohen's $d = 0.1$. In the children group, no effects were observed for either the medium, $t(13) = 2.17$, $p = .245$, Cohen's $d = 0.32$, or the long FP, $t(13) = .525$, $p = .609$ Cohen's $d = 0.14$ (see Figure 3).

Discussion

Results from Experiment 1 showed that school-age children could form time-based event expectancy. In addition, we did not find evidences that this effect was weaker in children than in adults, since there was no interaction between Group and Validity. However, we found that time-based expectancy was markedly different for children and adults. Namely, while adults showed a significant expectancy effect at longer FP, but children showed a significant expectancy effect at the shorter FP. Related to the temporal representational mode of time-based event expectancy, results showed that adults responded faster after the long FP in the test phase for the target that had been frequent at the medium FP in the learning phase confirming that time-based expectancy operates on relative representations of time in young adults. However, concerning children results were not conclusive. We did not find evidence that in children, like adults, time-based expectancy operates on relative representations of time. Children formed time-based expectancy at short FP (200 ms) in the learning phase, but they did not transfer their expectancy to the relative shorter FP (i.e. 800 ms) in the test phase. This finding might suggest that, in children, time-based expectancy operates on absolute representations of time, but we were not able to test this directly. As, contrary to our expectation, children formed timed-based expectancy only at 200 ms FP, not at 800 ms FP. Therefore, we were not able to test whether a potential time-based expectancy for 800 ms would have transferred in absolute terms to 800 ms in the test phase, and 200 ms did not occur in absolute terms in the test, so a potential transfer could not be tested for that FP. On the other hand, some

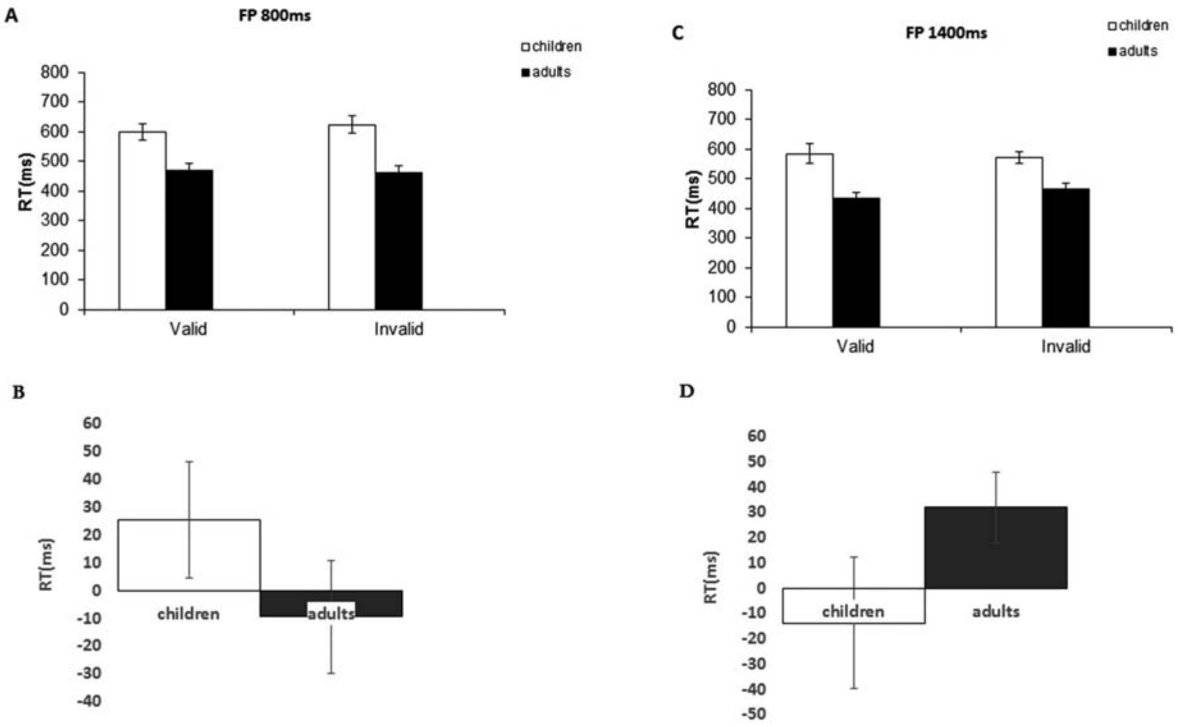

Figure 3. Test phase (Block 5). (A) The mean RTs at the *relative* short (800 ms) FP (medium in the learning phase), (B) magnitude of the Validity effect at the *relative* short (800 ms) FP (medium in the learning phase), (C) the mean RTs at the long (1400 ms) FP and (D) the magnitude of the Validity effect on RTs at the relative long (1400 ms) FP. Error bars represent the standard error of the mean.

participants from the children group may still employ absolute representations of time and some already employ relative representations due to a different time course of development of timing ability.

Experiment 2

Experiment 1 showed that the formation of time-based event expectancies was restricted to the shorter FP (200 ms) in children and they did not transfer their expectancy effect from the learning phase to the test phase. One potential reason for the lack of transfer might be that children, first, form time-based expectancies only for the shorter one of a pair of intervals, and, second, employ absolute time representations. Both assumptions together would have prevented transfer in Experiment 1, because the short FP of 200 ms did not appear in the test phase. Experiment 2 was designed to explicitly test these assumptions, by employing an 800 and 1400 ms pair of intervals during the learning phase, and a 200 and 800 ms pair of intervals during the test phase. Here, we expected, if relatively shorter intervals enable children to make more optimal temporal predictions, they would show more behavioural benefits after 800 ms (shorter) than after 1400 ms (longer) in the learning phase. But now this time-based expectancy should transfer to the test phase even if they base their expectancy on absolute intervals, because the FP of 800 ms is also displayed in the test phase.

Method

Participants

Sixteen right-handed children aged 8–12 (nine male, mean age = 9.75, SD = 1.12 years) and 20 right-handed adults aged 18–23 participated (eight male, mean age = 19.3, SD = 1.3 years). Three children were 8 years old, two were 9 years old, eight were 10 years old, two were 11 years old and one 12 years old. None of participants of Experiment 2 took part in Experiment 1. Verbal informed consent was obtained from all participants, while written informed consent was obtained from the parents of all children and from all adult participants.

Apparatus

The apparatus was the same as in Experiment 1.

Procedure

The procedure was the same as in Experiment 1, with the exception of FPs durations. Here, in the learning phase, the participants adapted to a longer pair of FPs (800 and 1400ms) and target's location combinations, with a probability of 80%.

In a following test phase (5th block), the long FP was replaced by a shorter one (200 ms), but the medium FP (800 ms) appeared again, and FP–target's location correlation became neutral (50%) (see Figure 1B).

Data analyses

The screening procedure was the same as described in Experiment 1. In total, 2.74% of all trials were excluded from the test phase, and 2.2% of all trails from the last block of the learning phase.

Results

Formation of time-based expectancy: learning phase

In the learning phase, an ANOVA of the mean RT showed main effects for the within-subjects factor of Foreperiod, $F(1,34) = 18.31$, $p < .0001$, $\eta^2 = 0.35$, but not for Validity, $F(1,34) = 2.2$, $p = .15$, $\eta^2 = 0.06$. There was a significant three-way interaction between Age Group, Foreperiod and Validity, $F(1,34) = 4.44$, $p = .043$, $\eta^2 = 0.116$. However, there was no interaction between Age Group and Validity, $F(1,34) = 0.63$, $p = .43$, $\eta^2 = 0.018$, and between Age Group and Foreperiod, $F(1,34) = .001$, $p = .977$, $\eta^2 = 0.00$. An interaction for FP*Validity showed only marginally significant trend, $F(1.34) = 3.77$, $p = .06$, $\eta^2 = 0.1$.

Separate ANOVA for both groups showed a significant main effect of Foreperiod for children, $F(1,15) = 7.26$, $p = .017$, $\eta^2 = 0.326$, and for adults, $F(1,19) = 11.57$, $p = 0.003$, $\eta^2 = 0.378$. The interaction between FP*Validity was significant for children, $F(1,15) = 5.22$, $p = .037$, $\eta^2 = 0.29$, due to participants in the children group responded faster at the valid trials ($M = 603$ ms, SD = 132) compared to the invalid ones ($M = 644$ ms, SD = 165) for the long but not the medium FP (valid: $M = 680$ ms, SD = 156; invalid: $M = 649$ ms, SD = 145). There was no such significant interaction between FP*Validity in the adults group, $F(1,19) = 0.02$, $p = .88$, $\eta^2 = 0.001$. However, there was a significant Validity effect for adults group, $F(1,19) = 4.4$, $p = 0.049$, $\eta^2 = 0.188$ but not for children, $F(1,15) = 0.15$, $p = .7$, $\eta^2 = 0.01$.

Follow-up t-tests for individual FPs showed a Validity effect at the long FP for the children, $t(15) = 2.31$, $p = .035$, Cohen's $d = 0.57$, but not for the adults, $t(19) = 1.34$, $p = .195$ Cohen's $d = 0.29$, There was no such effect at the medium FPs for both groups (children, $t(15) = 1.39$, $p = .183$, Cohen's $d = 0.34$, adults, $t(19) = 1.27$, $p = .218$ Cohen's $d = 0.28$) (see Figure 4).

Transfer of time-based expectancy: test phase

A mixed ANOVA with the between-subjects factor Age Group (children vs. adults) and the within-subjects factors Foreperiod (medium vs. long) and Validity (valid vs. invalid) on RT showed main effect for the within-subjects factor FP, $F(1,34) = 56.47$, $p < .0001$, $\eta^2 = 0.624$, but not for Validity, $F(1,34) = 1.83$, $p = .184$, $\eta^2 = 0.051$. There was a marginal two way interaction between FP*group, $F(1,34) = 3.84$, $p = .058$, $\eta^2 = 0.102$. No other interaction was significant (Validity*group, $F(1,34) = 0.14$, $p = .71$, $\eta^2 = 0.004$; Validity*FP, $F(1,34) = 0.24$, $p = .63$, $\eta^2 = 0.007$; Age Group*Foreperiod* Validity, $F(1,34) = 0.29$, $p = .59$, $\eta^2 = 0.009$).

Separate ANOVA for both groups showed significant main effects of FP, for adults, $F(1,19) = 30.03$, $p < .0001$, $\eta^2 = 0.612$ and for children, $F(1,15) = 26.33$, $p < .0001$, $\eta^2 = 0.637$. There was also a significant Validity effect for adults $F(1,19) = 5.47$, $p = .03$, $\eta^2 = 0.224$ but not for the children, $F(1,15) = .23$, $p = .638$, $\eta^2 = 0.015$. The interaction between Validity and FP was not significant for both groups (for adults, $F(1,19) = 1.52$, $p = .23$, $\eta^2 = 0.074$; for children $F(1,15) = 0.00$, $p = .98$, $\eta^2 = 0.00$).

Follow-up t-tests for individual FPs showed a Validity effect at the medium FP for adults, $t(19) = 3.4$, $p = .003$, Cohen's $d = 0.76$, due to adults responded faster at the combination of 800 ms with the event that had been frequent at 1400 ms in the learning phase. However, there was no such effect at the short FP for adults, $t(19) = 0.236$, $p = .816$, Cohen's $d = 0.05$. There was no Validity effect for children neither at medium FP, $t(15) = 0.3$, $p = .769$, Cohen's $d = 0.07$ nor at short FP, $t(15) = 0.298$, $p = .77$, Cohen's $d = 0.07$ (see Figure 5).

Discussion

In Experiment 2, again, we replicated findings that adults employ relative representations of time for time-based expectancy. We found that young

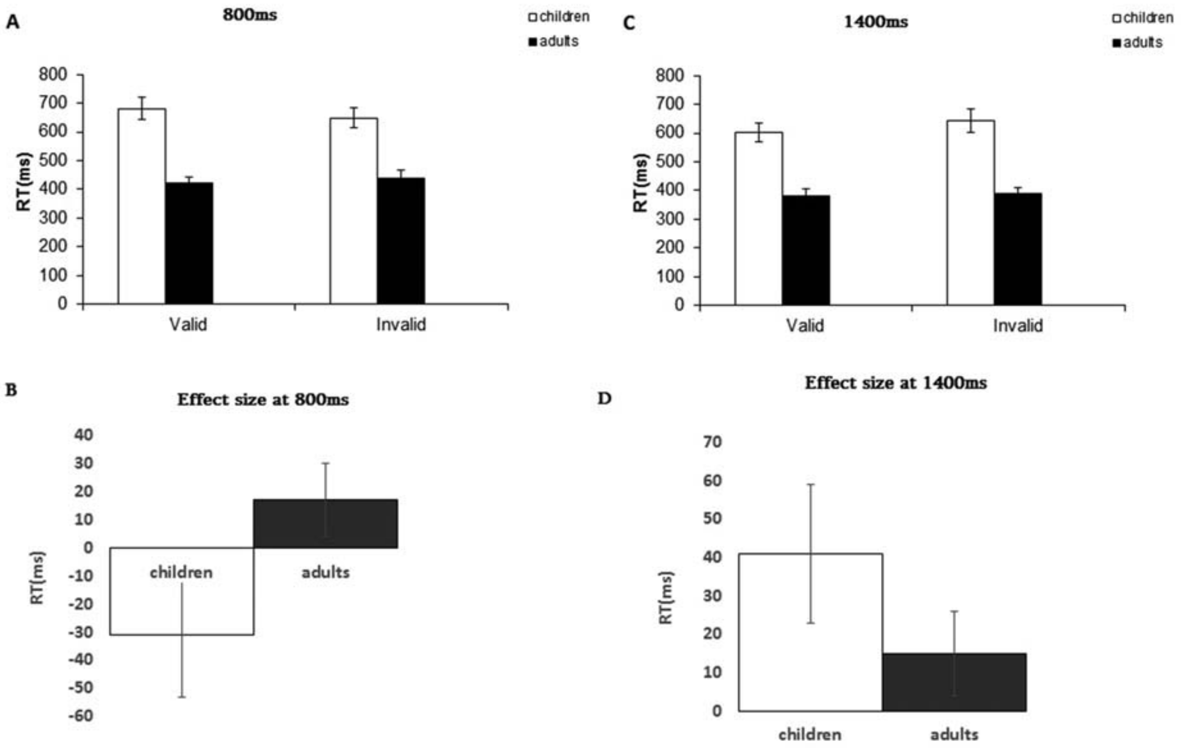

Figure 4. The learning phase (Block 4). (A) The mean RTs at the median (800 ms) FP, (B) magnitude of the Validity effect at the median (800 ms) FP. (C) The mean RTs at the long (1400 ms) FP. (D) Magnitude of the Validity effect at the long (1400 ms) FP. Error bars represent the standard error of the mean.

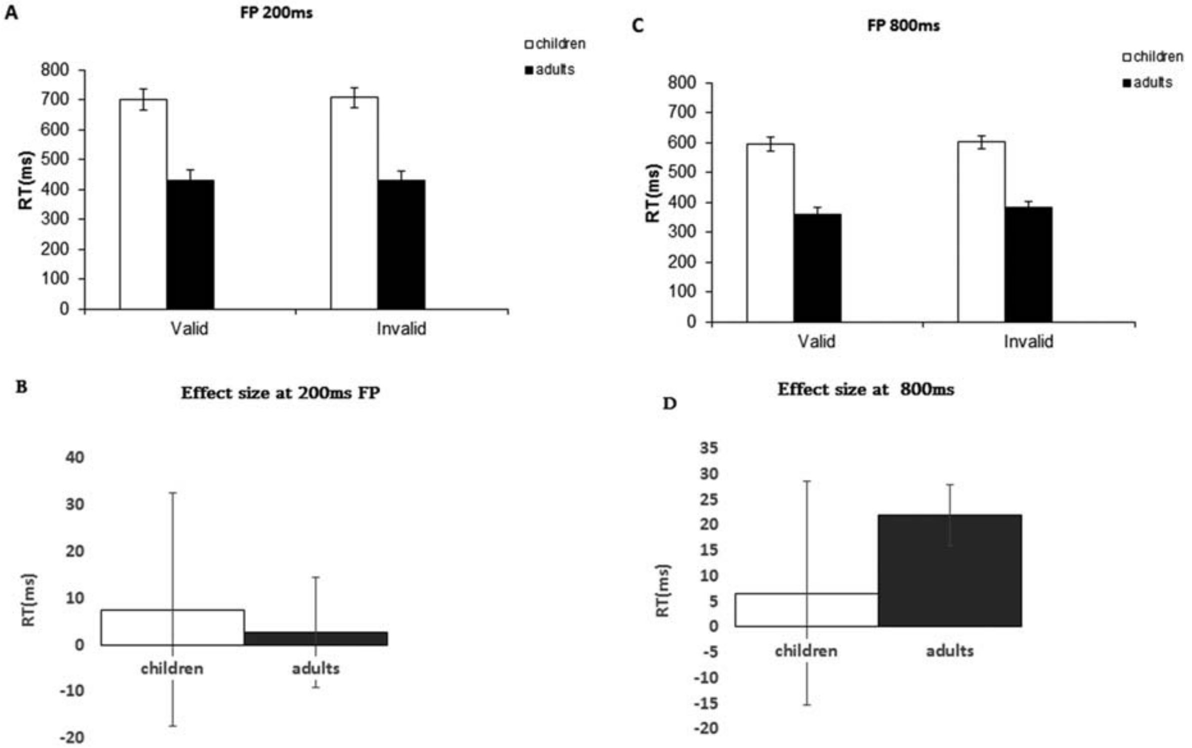

Figure 5. Test phase (Block 5). (A) The mean RTs at the relative short (200 ms) FP. (B) The magnitude of the Validity effect on RTs at the relative short (200 ms) FP. (C) The mean RTs at the relative long (800 ms) FP (medium in the learning phase). (D) The magnitude of the Validity effect on RTs at the relative long (800 ms) FP. Error bars represent the standard error of the mean.

adults, in the test phase, responded faster at the combination of the longer FP with the event that had been frequent at the long FP in the learning phase, suggesting they transferred expectancy according to relative representations of time. Results from Experiment 2 confirmed findings from Experiment 1 that children can form time-based expectancy. But, different from Experiment 1, they form time-based expectancy only at the longer FP. However, in contrast to adults, children, as in Experiment 1, did not show any signs of a transferring of their expectancy from the learning phase to the test phase. Yet, it is still unclear whether this lack of observable transfer is due to differences in representational mechanisms among children participants (i.e. some rely on absolute others relative representations), or due to an absolute representation of time in time-based expectancy for all children. Again, the time-based expectancy was formed only for a FP, which did not reappear in test phase. Yet, contrary to our expectation, it was now the longer FP. So, again, time-based expectancy in absolute terms would not have been able to transfer.

General discussion

We investigated time-based event expectancy in school-aged children and in adults. In the first part of Experiment 1 and Experiment 2 (learning phase), children aged 8–12 years and adults aged 18–35 years were trained to associate two choice-responses to different FPs. Children showed a strong variable FP effect, i.e. they responded faster to longer than to shorter intervals (Los & van den Heuvel, 2001, Los et al. 2001; Steinborn et al., 2008, 2009), suggesting that they were able to differentiate between the different interval durations. Previous studies have also found children to show variable FP effects (Johnson et al., 2015; Vallesi & Shallice, 2007).

With regard to time-based expectancy, we found that children, in both Experiments, responded faster to frequent combinations of FP–target's localisation than to infrequent combinations, suggesting that they formed time-based event expectancy. Our finding is in good accordance with previous studies that showed that school-age children were able to improve their performance by using information provided by external discrete temporal cues (Mento & Tarantino, 2015; Mento & Vallesib 2016). Taken together, these results and results from our study suggest that school-aged children not only can use temporal cues to improve their performance but also can predict upcoming events based on the duration of waiting time.

However, we found that time-based event expectancy was restricted to shorter FP (i.e. 200 ms) for children and to the longer FP (i.e. 800 ms) for adults in Experiment 1. Our previous studies also showed that in young adults, time-based expectancy was more pronounced with the longer one of the two FPs (Thomaschke et al., 2015). Likewise, in Experiment 2, school-age children showed a Validity effect at the longer FP (i.e 1400 ms) as well. It seems that for school-age children, in contrast to younger adults, neither shorter nor longer pre-target intervals are particularly optimal for making temporal predictions. Rather, they formed time-based event expectancy at the 200 ms FP in Experiment 1, and at the 1400 ms FP Experiment 2, but did not form expectancies in any of the experiments at the 800 ms FP.

A possible interpretation to reconcile the findings from both experiments is that children form time-based expectancies only for intervals which are unusual in the current context. Intervals of about 800 ms are quite typical system response intervals in human–computer interaction, while 200 is unusually short and 1400, for simple interactions, rather long (Seow, 2008). When system responses are more instantaneous than usual (like with 200 ms), or when there is an obvious delay (like for 1400 ms), attention is attracted to the following event. This attention might be a precondition for children for forming implicit associations between points in time and events, that is, for the formation of time-based expectancy. As the effect comes after a typical computer-interaction interval in the 800 ms condition, participants' attention is not attracted to the event timing, and thus it gets not associated with an event to the same degree as the atypical intervals do. Note, however, that this interpretation is speculative, at it assumes that either adult's attentional capture by unusual timing is lower or that adults do rely less on attention capture in forming time-based expectancies. Yet, both assumptions cannot be verified by the current experiment, but would require further experiments, for example, manipulating 'typicality' of an interval directly.

Another strategy to test this speculation in future studies would be to take participants' computer game experiences into account. When participants would report their gaming experiences in a sufficiently detailed way, one might infer from these information which kind of 'typical' system RT, the individual participants are commonly exposed to in their everyday life computer game contexts. Previous research has shown that computer game experience does have a reliable and systematic impact on timing performance (Donohue et al., 2010). For example, video gameing children showed enhanced performance in spatial, temporal and object-based aspects of visual selective attention when compared with non-gamers (Dye & Bavelier, 2010). In sum, our findings from the learning phase suggest that both the variable FP effect and the ability to form time-based event expectancy were developed in school-aged children. Yet, children seem to form time-based expectancy primarily for context-atypical, and hence salient, FPs.

In the second part of Experiments 1 and 2 (test phase), we investigated whether children, like adults, employ relative duration representations for time-based expectancy. The formerly short or long interval was replaced by a new one, which was longer or shorter than the previous interval, and both events appeared equally often after both intervals, so that no new time-based event expectancy was induced.

As in the learning phase, time-based expectancy was markedly different for children and adults. In Experiment 1, we found that adults responded faster after the long FP in the test phase for the target that had been frequent at the medium FP in the learning phase. This speaks in favour of relative representations, because in the test phase, the long FP is actually the relatively longer FP, as there was only a medium and long FP in the test phase. In Experiment 2, adults also showed the same temporal representational mode of time-based event expectancy as in Experiment 1. However, children did not transfer time-based expectancy from the learning to the test phase in both Experiments.

Previous studies also suggest that time-based expectancy in adults relies on relative time representations (Kunchulia & Thomaschke, 2016; Thomaschke et al., 2015), as opposed to general timing abilities which employ absolute representations of time (Creelman, 1962; Gibbon, 1977; Treisman, 1963). Our findings might suggest that children did not associate the stimulus response events with the binary categories 'early'/'late', and instead relied on absolute metric representations of the FPs during the formation of time-based expectancy. This would be in line with previous findings showing that the ability to temporally categorise familiar actions improves from childhood to adulthood (Rattat & Tartas, 2017).

However, this conclusion relies on indirect reasoning, and we did not provide direct positive evidence for the use of absolute representations of time in children. Because children did in neither experiment form time-based expectancy for 800, and 800 was the only FP repeated in the transfer phase, absolute transfer could not be tested. Future studies would need to establish positive evidence for absolute representations of time for time-based expectancy in children, for example, by employing short and long FPs which are both salient by being unusual in a computer context. Note, however that our study did not target the question of whether children can in general process time in an absolute or a relative manner or both. We only tested whether potential absolute or relative interval representation would be employed for time-based expectancy. Thus, our failure to find relative time processing in time-based expectancy does not suggest that children have generally reduced ability to process time in a relative manner.

Another explanation would be that the sample of children was not homogenous with regard to their use of time representations, because the age range spanned a developmental period where the use of absolute transforms to relative. Yet again, this conclusion would only be speculative, and future studies would need to confirm this, for example, by a narrower age range.

While the present study juxtaposed two disparate age groups, it is an important question for future research to determine the developmental time course between the ages represented by these groups. With participants spanning in a more continuous manner between children and young adults, also including adolescents, one could determine at exactly which developmental stage the child-typical expectancy pattern transforms into an adult-typical pattern.

In conclusion, we found that school-aged children can form time-based event expectancy and, in contrast to adults, this time-based expectancy seems to be especially strong for unusual FPs in the current context. Further, we showed that children, in contrast to adults, do not uniformly employ relative representations of time in time-based expectancy. Yet, it is not clear whether they uniformly employ absolute representations, or whether they employed inter-individually different representational mechanisms. Our findings provide an important piece in the puzzle to better understand the development of temporal expectation in school-aged children. However, these findings require further studies with narrower age ranges of children to investigate the developmental time course of time-based expectancy and the ability to temporally categorise events in children.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data are available from the corresponding author on reasonable request.

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