Rethinking attention in time: expectancy violations reconcile contradictory developmental evidence

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Abstract

Temporal expectations critically influence perception and action. Previous research reports contradictory results in children's ability to endogenously orient attention in time, as well as the developmental course. To reconcile this seemingly conflicting evidence, we put forward the hypothesis that expectancy violations–through the use of invalid trials–are the source of the mixed evidence reported in the literature. With the aim of offering new results that could reconcile previous findings, we tested children aged 4 to 7, an older group aged 8 to 12, and adults. Temporal cues provided expectations about target onset time, and invalid trials were used such that the target appeared at the unexpected time in 25% of the trials. In both experiments, the younger children responded faster in valid than invalid trials, showing that they benefited from the temporal cue. These results show that young children rely on temporal expectations to orient attention in time endogenously. Importantly, younger children exhibited greater validity effects

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than older children and adults, and these effects correlated positively with participants' performance in the invalid (unexpected) trials. We interpret the reduction of validity effects with age as an index of better adaptation to the invalid (unexpected) condition. By using invalid trials and testing three age groups, we demonstrate that previous findings are not inconsistent. Rather, evidence converges when considering the presence of expectancy violations that require executive control mechanisms, which develop progressively during childhood. We propose a distinction between rigid and flexible mechanisms of temporal orienting to accommodate all findings.

Introduction

In our daily lives, we face multiple situations in which the properties of a given stimulus capture our attention automatically, irrespective of our internal goals. For instance, while walking on the street, the sound of an ambulance may drive our attention to its location in an automatic manner. We can also orient our attention voluntarily according to our current goals, such as when looking towards the left side of the street when expecting our late-coming bus to arrive from that location. These two different forms of attention are *exogenous* and *endogenous*, respectively. This distinction is well-established in cognitive neuroscience literature, both in visuo-spatial attention—i.e. the allocation of attention to a specific location (Corbetta & Shulman, 2002; Corbetta, Patel, & Shulman, 2008) and in the temporal attention field—i.e. the allocation of attention to a particular point in time (Coull & Nobre, 1998; Coull, Vidal, Nazarian, & Macar, 2004).

Orienting mechanisms of attention

Previous research showed that Attention is not a unified entity, but composed of three different attentional systems (Posner & Petersen, 1990; Petersen & Posner, 2012): alerting, orienting and executive. Among these, the orienting system refers to the ability to prioritize sensory input by selecting a modality or location. In a typical endogenous spatial orienting task, attention is voluntarily directed to one location in response to predictive cues (e.g., arrows) that provide information about where an upcoming target is likely to appear (Posner, 1980). When participants make use of this endogenous cue, they are faster in detecting targets appearing in validly cued positions compared to invalidly cued locations (Posner & Petersen, 1990; Petersen & Posner, 1990). For many decades, most of the research on attention was focused on the visuo-spatial domain. In the last three decades, a wealth of work has also focused on the temporal domain, and yet temporal orienting of attention is far from being well understood.

Temporal orienting of attention

Temporal orienting of attention belongs to the research field of timing, which investigates the cognitive mechanisms of temporal expectations. Temporal expectation is a wide-ranging concept that consists of many forms of attentional preparation in time involving a prediction about when a forthcoming event will occur (Coull, Frith, Büchel, & Nobre, 2000; see Correa, 2010 for a review). Temporal expectations benefit perception, action, and learning (Correa, Lupiáñez, Madrid, & Tudela, 2006; Lange, Krämer, & Roeder, 2006; Martens & Johnson, 2005; Milliken, Lupianez, Roberts, & Stevanovski, 2003; Naccache, Blandin, & Dehaene, 2002; Rohenkohl, Gould, Pessoa, & Nobre, 2014), thus having a critical role in cognition.

Temporal expectations rely on different sources to provide the relevant temporal information. Four of these sources have been well-identified in the literature: probabilistic information associated with the passage of time, repetition of the same type of durations, rhythmicity, and temporal information set by explicit predictive cues (see Correa, 2010 for a review). The first three types of temporal expectations are associated with *exogenous* attention mechanisms, and promote foreperiod, sequential, and rhythmic effects, respectively. The fourth type of temporal expectation is associated with *endogenous* mechanisms of attention; that is, the ability to use predictive temporal information to orient attention in a goal-directed manner (Coull & Nobre, 1998; Coull et al., 2000). This type of endogenous attention mechanism will be the focus of the current study.

In a pioneering study on this topic, researchers examined whether knowing when an event will occur allows our attentional resources to be directed towards a point in time to optimize our behavior (Coull & Nobre, 1998). Adults were presented with temporal cues which predicted the temporal interval in which a target was most likely to appear, either an *early* or a *late* expectancy cue (i.e., expect the target to appear after a *short* or a *long* time interval, respectively). After the target onset, reaction times (RT) to its appearance were measured (Coull & Nobre, 1998). The cue-target Stimulus Onset Asynchrony (SOA) was manipulated, such that the target actually appeared either at the validly or invalidly cued time interval. Results revealed faster RTs for targets appearing at expected compared to unexpected time intervals. These results showed for the first time that adults can use temporal predictions to orient attention in time to benefit behavior (Coull & Nobre, 1998). After this ground-breaking study, three decades of research have provided the field with numerous invaluable pieces of evidence of the benefits in behavior of orienting attention in time in adults (Correa, Cona, Arbula, Vallesi, & Bisiacchi, 2014;

Correa, Lupiáñez, Milliken, & Tudela, 2004; Coull et al., 2000; Davranche, Nazarian, Vidal, & Coull, 2011; Heideman et al., 2018; Sanabria, Capizzi, & Correa, 2011), including the elderly population (Chauvin, Gillebert, Rohenkohl, Humphreys, & Nobre, 2016).

Developmental trajectory of temporal orienting of attention

In recent years, developmental research has sought to determine whether children are able to use temporal expectancies to orient attention endogenously in time (Johnson, Bryan, Polonowita, Decroupet, & Coull, 2016; Johnson, Burrowes, & Coull, 2015; Mento & Tarantino, 2015; Mento & Vallesi, 2016), and when this ability emerges in infancy (Martinez-Alvarez, Pons, & De Diego-Balaguer, 2017). Such developmental studies have been essential in starting to uncover how the mechanisms of temporal orienting unfold both in typical (Johnson et al., 2015, 2016; Mento, Scerif, Granziol, Franzoi, & Lanfranchi, 2019; Mento & Tarantino, 2015; Mento & Vallesi, 2016, Martinez-Alvarez et al 2017) and atypical development (Mento, Scerif, Granziol, Franzoi, & Lanfranchi, 2019). Moreover, these investigations are currently of particular importance since recent proposals postulate that temporal orienting abilities may assist or boost other aspects of cognitive development that involve temporal processing, such as language (de Diego-Balaguer, Martinez-Alvarez, & Pons, 2016). Unfortunately, the available evidence on typically developing children provides inconsistent results in at least two respects.

Inconsistencies in the results of previous studies

First, although temporal orienting abilities can be observed at 15 months of age (Martinez-Alvarez et al., 2017), whether or not these are found in children is still controversial. The first study to investigate endogenous temporal orienting of attention in infancy tested 12- and 15-month-olds using an anticipatory eye movement procedure to measure whether infants are able to anticipate a specific time interval predicted by an endogenous temporal cue (Martinez-Alvarez et al., 2017). Results indicated that at 15 months of age infants show anticipatory behavior based on the temporal information provided by the cue. This evidence suggests that endogenous mechanisms to orient attention in time emerge by the second year of life. These findings converge with data from 6-year-old children showing that they can orient attention in time endogenously, based on a temporal cue (Mento & Tarantino, 2015, as well as with data from typically developing younger children aged 4 to 6 years (Mento et al., 2019). However, these results are in sharp contrast with two studies with older children (mean age: 11 years), where children were unable to orient attention in time endogenously in the absence of exogenous cues (Johnson et al., 2015; 2016).

Taken together, the available developmental evidence seems to suggest that an ability found at the early age of 15 months (Martinez-Alvarez et al., 2017) and present also at 4 to 6 years of age is no longer detectable at the age of 11 years (Johnson et al., 2015; Johnson et al., 2016). Crucially, both the results in infants (Martinez-Alvarez et al., 2017) and in young children (Mento & Tarantino, 2015; Mento et al., 2019) could not be explained by exogenous effects.

The second source of inconsistency in results concerns the stabilization vs. progression of temporal orienting abilities through development. Mento & Tarantino (2015) found no differences when comparing the performance of children aged 6-7 years, 8-9 years, 10-11 years, and adults. That is, all age groups showed abilities comparable to adults, suggesting that at 6 years of age endogenous temporal orienting abilities are fully developed. In contrast, Johnson et al. (2016) found that when temporal abilities could be observed (by adding exogenous cues), temporal orienting abilities significantly differed from adults. This result is even more surprising given that the group of children studied was older (mean age 11 years) compared to the oldest group from the Mento & Tarantino (2015) study. What might explain such inconsistency of results? The main goal of the present study is to offer and test a hypothesis that reconciles this apparently contradictory evidence.

Commonalities and differences in the designs of previous studies

As discussed in both studies above, spatial predictability could be a potential source of conflicting evidence in relation to the presence of endogenous temporal orienting effects in children. Target presentation was central, and therefore always spatially predictive, in Mento & Tarantino (2015), rather than lateralized (either right or left) (Johnson et al., 2015; 2016). In the infant study (Martinez-Alvarez et al., 2017), target presentation was lateralized but also fully spatially predictive based on the identity of the cue. It is known that the benefit of temporal cues is enhanced when the target location is fixed and spatially predictable (Rohenkohl et al., 2014). Therefore, it is likely that the spatial predictability of the target allowed infants and younger children to benefit from temporal cues.

Another potentially critical source of conflicting evidence is the measurements used to assess children's temporal orienting abilities. The commonality among all studies is the presence of cues that contain a *temporal expectancy* (the so-called 'valid' or ‘predictive’ condition). Yet they differ in the condition used to compare the temporal expectancy, with either a neutral (non-predictive) or an invalid (unexpected) condition. Consequently, temporal orienting effects were defined either by a) a decrease in RT as a consequence of a temporal expectation, comparing temporal predictive to a neutral (non-predictive) condition (Mento & Tarantino, 2015; Mento & Vallesi, 2016; Mento et al., 2019), or b) as a consequence of a match between temporal expectancy of an event and the actual temporal occurrence of that event (valid condition) compared to a mismatch (invalid condition) (Johnson et al. 2015; 2016).

When children are presented with a neutral condition that does *not* violate their temporal expectations, significant temporal orienting effects are found, and no differences in performance are observed when comparing children of different ages and adults (Mento & Tarantino, 2015; Mento & Vallesi, 2016). In contrast, when children are presented with an invalid condition that violates their temporal expectations endogenous temporal orienting effects are harder to observe. In this case temporal orienting abilities are absent (Johnson et al., 2015, and Experiment 1 in Johnson et al., 2016) or, if present, developmental differences between older children and adults are observed (Experiment 2 in Johnson et al., 2016).

As we will argue here, the presence of the unexpected condition could be a potential underlying source of the inconsistent pattern of previous results, especially if one aims at convergence of all the available developmental evidence including the presence of endogenous mechanisms of temporal orienting in infancy (Martinez-Alvarez et al., 2017).

Our hypothesis: the presence of expectancy violations modulates temporal predictions

Here we put forward the hypothesis that the inconsistent results stem from the fact that the temporal expectancies were *violated* in some of the studies (Johnson et al., 2015, 2016), but *not* in others (Martinez-Alvarez et al., 2017; Mento & Tarantino, 2015; Mento et al., 2019). By expectancy violation we mean the presence of a condition that is in conflict with the temporal expectancy determined by the temporal cue. The concept of expectancy violation is not a new notion but rather has been widely used in other domains (see Summerfield & Egner, 2009 for a review). Although the notion of expectancy violations has already been introduced in the temporal orienting (Lange, 2013) and infants’ learning fields (Stahl & Feigenson, 2015), developmental research investigating temporal orienting has overlooked the influence of this factor.

Expectancy violations could have a critical effect in temporal orienting since they may engage executive mechanisms to a certain extent. Executive attention mechanisms control how our attention is directed according to our goals, by detecting and resolving conflict (Posner & Petersen, 1990; Petersen & Posner, 1990), and they show a progressive development throughout childhood (Pozuelos, Paz-Alonso, Castillo, Fuentes, & Rueda, 2014; Rueda et al., 2004). Classically, executive attention has been measured with tasks that involve conflict (see Conejero & Rueda, 2017 for a review) such as the Flanker task. Adaptations of the classical Posner paradigm have been developed including Flankers to differentially measure orienting and executive attention mechanisms in the same task (Rueda, Fan, et al., 2004). In these versions, the central cue is surrounded by flankers that point in the same or opposite direction of the central cue. Conflict is measured comparing these two conditions. While the comparison between valid and invalid trials provides a measure of validity effects considered to reflect only orienting mechanisms of attention, it is critical to consider that an invalid trial also requires dealing with conflict. In invalid trials individuals need to refrain from giving a predominant—but now inappropriate—response and switch to the non-dominant response that is now required. In this sense it is critical that greater validity effects could be the result from faster RTs in the valid condition or slower RTs in the invalid condition. Since conflict does not affect valid trials, the development of the ability to deal with conflict should mainly affect invalid trials.

When participants have low conflict abilities, the high reliance on the predominant response and the difficulty in switching to the non-dominant response should lead to high dispreparation in the invalid (unexpected) condition. In contrast, when participants have greater flexibility to deal with conflict, they are expected to be relatively prepared in the invalid, less expected condition, reducing validity effects. However, increased flexibility should also allow individuals to be relatively prepared in invalid trials that are less likely but still possible to occur, reducing validity effects. Hence, observing whether the differences in validity effects derive specifically from differences in invalid conditions should be informative of how participants deal with conflict.

Here we hypothesize that, when measuring children's temporal orienting effects using invalid conditions that involve expectancy violations, greater validity effects derive from children's difficulty in flexibly adapting to expectancy violations, leading to slower responses in invalid conditions. As a consequence, greater validity effects may be observed in young children compared to older children and adults because the ability to deal with conflict is not sufficiently mature.

A first support for our hypothesis comes from the differences found between children and adults in Johnson et al. (2016). When age differences are found, children display larger orienting effects than adults (Johnson et al., 2016). That is, the older the participant, the smaller the temporal orienting effect. In this line, Johnson et al. (2016) argued that the age differences could be due to children's difficulty in responding to the invalid condition. However, their statistical analysis did not allow this conclusion to be drawn from their results.

The goal of the study

The objective of this study is to test a hypothesis that could reconcile the apparently contradictory evidence found in the developmental research of temporal orienting. First, we controlled spatial predictability, showing cue and target at the central location in our two experiments. By controlling for spatial predictability, we expected to replicate previous studies showing temporal orienting abilities in young children (Mento & Tarantino, 2015; Mento et al., 2019). Second and most importantly, we aimed to test whether the presence of expectancy violations might impact the developmental progression of temporal orienting of attention.

If, as we hypothesized, the magnitude of the validity effects through development is associated with adaptation to conflict, we predicted age differences and a direct relation between overall performance and the invalid condition. In this line, Johnson et al. (2015; 2016) found such differences when comparing 11-year-old children's and adults' performance using invalid trials in the experimental paradigm. The current study goes one step further and compares different age groups that were previously included in separate studies: a younger group of children (4-7 years) that overlaps and extends the younger group from Mento & Tarantino (2015) and Mento et al., 2019, and an older group (8-12 years) that overlaps with and extends the studies of Johnson et al (2015, 2016). Moreover, developmental differences in the ability to adapt to conflict are found especially from 8 years of life (Pozuelos et al., 2014; Simonds et al., 2007). Thus, the current three-group evaluation (4-7 years, 8-12 years, and adults) allows us to test and compare with previous studies whether developmental differences in temporal orienting arise between those critical age groups. Finally, we used two experimental designs differing in the weight of exogenous effects: a block design with a high degree of sequential effects (Experiment 1), and a trial-by-trial design with a lower degree of sequential effects due to the constant switch of temporal expectations (Experiment 2).

Experiment 1: Block design

Methods

Participants

One-hundred seventeen participants were tested. Eight participants were excluded due to exceeding 2 *SD* from the group mean accuracy (*n* = 3) or exceeding 2 *SD* from the group mean RT (*n* = 5). The final sample of 109 participants was divided into three groups: a group of fifty children younger than 8 years of age (4- to 7-years-old), a group of thirty-three children aged 8 years or older (8-12-years-old), and a group of twenty-six adults. Demographic characteristics of each group are reported in Table 1. A more detailed description of the demographic characteristics within each age group are reported in the Appendix. A power analysis was performed using the GPower software (Erdfelder, Faul, & Buchner, 1996) with the effect size from Johnson et al. 2016 (Effect size f = 0.5; a large effect under Cohen's 1988 standards), power set at = 0.80 and an alpha = .05. With these parameters the minimum sample size needed was 12; thus, our final sample size for each age group was largely powered for the main objective of this study. Children were recruited from a primary school in XX and adults were recruited from the undergraduate psychology population at the University of XX. The latter group took part in the experiment for course credit. All participants were tested by the same experimenter. All participants had normal or corrected-to-normal vision, no auditory problems, and no language development disabilities. Ethical approval of the protocol was obtained from the University of XX, in accordance with the 1964 Declaration of Helsinki. Parents provided written informed consent prior to each child's participation in the study.

Table 1. Main demographic characteristics of the participants in Experiment 1 (block design).

		Age		Gender		Handedness	
	n	Mean (SD)	Range	Female	Male	Left	Right
4-7 years	50	6.1 (1.1)	4.0 – 7.9	19	31	5	45
8-12 years	33	9.1 (1.0)	8.1 – 12.2	11	22	2	31
Adults	26	20 (1.3)	18 – 30	21	5	0	26

Age in years. Standard Deviation (SD) in parenthesis

Stimuli and procedure

Each trial began with a central fixation cross, presented for a jittered duration (750/1000/1250/1500 ms), allowing a variable inter-trial interval (ITI), followed by a 400 ms central temporal cue. In order to engage the children in the task and reduce the working memory load associated with remembering the time associated with the cue, the temporal cues used were semantically transparent. A color picture of a rabbit (expect-early cue) indicated that the target (a red apple) would appear after a short interval (200 ms from cue offset). A color picture of a turtle (expect-late cue) indicated that the target would appear after a long interval (1200 ms from stimulus offset). After the 400 ms temporal cue, a short (200 ms) or long (1200 ms) interval in which the screen remained white was displayed, and then the target appeared for 100 ms. All stimuli were displayed centrally on the screen at a viewing distance of 60 cm. Catch trials were also included to reduce the certainty of target appearance. These trials had the same structure but the target was not presented. The trial ended when a response was given or after a maximum of 1500 ms. The sequence of events in each trial type is illustrated in Figure 1. The presentation of stimuli and data collection were controlled using the Presentation software (Neurobehavioral Systems, Albany, NY, USA). The experiment was run on a PC connected to a 17-inch monitor at a resolution of 1280 x 1024 pixels.

The task consisted of a speedy target detection. Participants were instructed to press the space bar with the index finger of their dominant hand (assessed with the Edinburgh Handedness Inventory questionnaire; Oldfield, 1971) as quickly as possible at the target occurrence. They were also instructed not to press the button when the target was not present (i.e., catch trials). To encourage children to be engaged, we presented the experiment as a computer game in which they could feed two animals (the rabbit and the turtle) with an apple ('target') by pressing the space bar as soon as the apple appeared. Participants were explicitly informed about the temporal meaning of each cue (rabbit/'early cue' and turtle/'late cue'). The experiment included an expect-early block and expect-late block. In the expect-early block, the temporal cue (i.e., the rabbit) provided either valid temporal information (Valid trials – Short SOA) or invalid temporal information (Invalid trials – Long SOA). Because the block also contained catch trials (i.e., trials with no target), participants could not predict whether the target would eventually appear or not. Block order presentation was counterbalanced across participants.

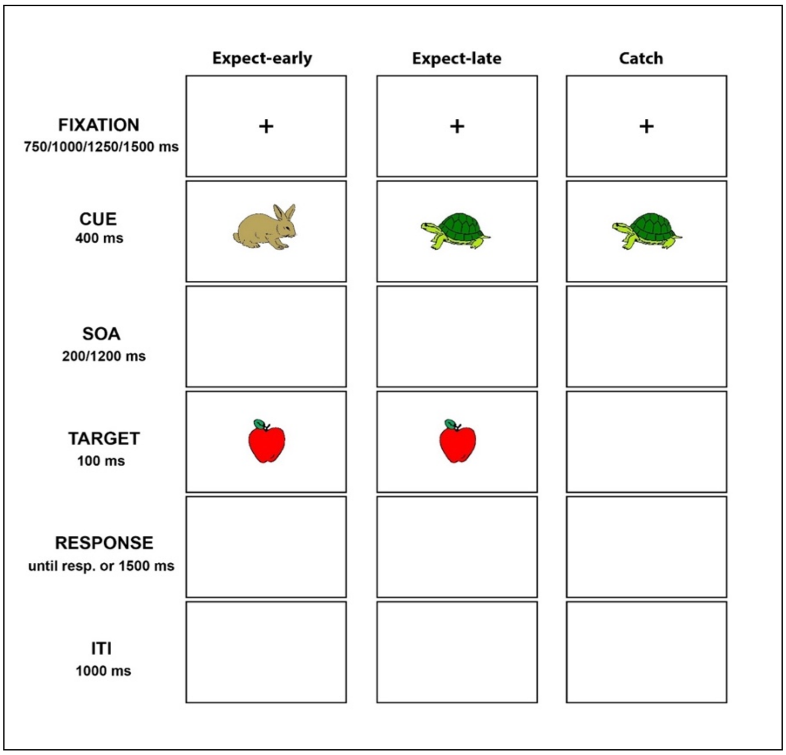

Figure 1. Sequence of events in each trial type (expect-early, expect-late, catch). The visual cue provided temporal information concerning the cue-to-target interval, which could be short (Expect-early trial) or long (Expect-late trial) with 75% validity. The target was not presented in catch trials.

There was a total of 64 trials per block: 56 trials with a target and 8 catch trials (12.5% of the block). The 56 target trials consisted of 42 validly cued trials and 14 invalidly cued trials, producing a validity percentage of 75%. Trials were pseudo-randomly presented such that (1) each block started with 7 valid trials, and (2) a catch trial or an invalid trial was always followed by a valid trial. This criterion was applied in order to preserve children's reliability on the temporal cue.

Before starting the experimental session, children underwent 2 training blocks (expect-early cue and expect-late cue) to ensure they understood task instructions. Only valid and catch trials were included during training. Participants received audiovisual feedback played automatically during the training session. The training session lasted until the participant reached 3 consecutive correct responses, one of which was always a catch trial. All children successfully completed the training phase. The experiment lasted approximately 20 minutes and participants were allowed to take a break between the blocks. Child participants performed the experimental task individually in a quiet room at their school. Adult participants completed the task individually in a sound-attenuated booth at the university.

Results

Mean RTs for each condition and participant were obtained. Omissions, anticipated responses (within the cue and 100 ms after target onset), and delayed responses (1500 ms after target onset) were considered errors and were excluded from analysis (Mento & Tarantino, 2015). Trials with RTs exceeding 2 *SD* from the individual average were excluded. The remaining responses were considered correct (Mento & Tarantino, 2015).

Age effects in temporal orienting

In order to analyse the age effects on temporal orienting, a mixed ANOVA was used with Validity (valid, invalid) as a within-participants factor and Age (4-7y, 8-12y, adults) and Order (block with expect-early cue first, block with expect-late cue first) as between-participants factors. Results yielded a significant main effect of Age [$F(2, 103) = 49.74$, $p < .001$, $\eta_p^2 = .49$], Validity [$F(1, 103) = 363$, $p < .001$, $\eta_p^2 = .78$], and a Validity by Age interaction [$F(2, 103) = 14.85$, $p < .001$, $\eta_p^2 = .22$]. This interaction was broken down by Age. In all three age groups there was a significant difference between valid and invalid conditions: 4-7 years [$t(49) = 14.9$, $p < .001$, $d = 2.11$], 8-12 years [$t(32) = 11.0$, $p < .001$, $d = 1.9$], and adults [$t(25) = 9.52$, $p < .001$, $d = 1.87$]. All three groups of participants responded to Valid trials significantly faster than they did to Invalid trials. Therefore, the Age by Validity interaction was explained by the decrease in the magnitude of the effects as a function of Age (see Figure 2A). That is, younger children revealed greater effects ($M = 112$, $SD = 53$) compared to older children ($M = 76$, $SD = 39$), $t(81) = 3.41$, $p = .001$, $d = 0.76$], and compared to adults ($M = 58$, $SD = 31$), $t(74) = 4.77$, $p < .001$, $d = 1.31$].

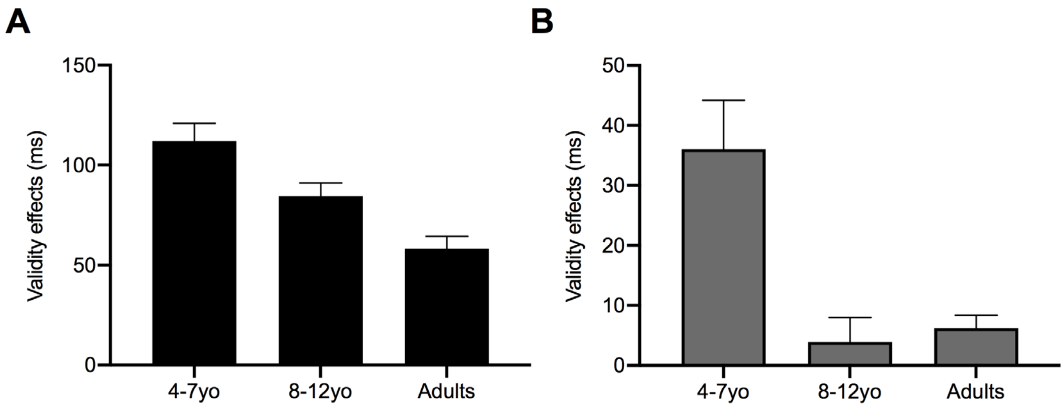

Figure 2. A) Validity effects (calculated by subtracting the reaction times (RT) at valid condition to RT at invalid condition) per each age group in Experiment 1 (block design). **B)** Validity effects per each age group in Experiment 2 (trial-by-trial design). Error bars reflect standard errors.

Moreover, a significant main effect of Order [$F(1, 103) = 7.97$, $p = .006$, $\eta_p^2 = .07$] and a Validity by Order interaction [$F(1, 103) = 8.893$, $p = .004$, $\eta_p^2 = .08$] were observed.

In both Order types there was a significant difference between valid and invalid conditions: early-expectancy first [$t(55) = 15.25$, $p < .001$, $d = 2.0$], early-expectancy last [$t(52) = 11.63$, $p < .001$, $d = 1.6$]. The Validity by Order interaction was due to a greater magnitude of the effects in those participants starting with the expect-early block (M = 102, SD = 50) compared to participants starting with the expect-late block (M = 74, SD = 46), $t(107) = 3.04$, $p = .003$, $d = 0.60$]. The difference in magnitude was due to shorter RTs in the valid trials in the expect-early block group (M = 333, SD = 68) compared to the expect-late block group (M = 375, SD = 74), $t(107) = 3.11$, $p = .002$, $d = 0.60$. Block order did not affect RTs in the invalid trials [$t(107) = .78$, $p = .436$]. There was no Age by Order interaction [$F(2, 103) = 0.015$, $p = .98$], nor was there a Validity by Age by Order interaction [$F(2, 103) = 0.44$, $p = .65$]. Therefore, the order effects were comparable in the all age groups, affecting only performance in the valid condition.

Developmental trend of temporal orienting effects.

In order for our results to be comparable to previous studies, in the above-presented ANOVA we first analyzed age as a categorical variable (with participants being divided in three age groups). Nevertheless, given the nature and age distribution of the collected sample, we were able to analyze age as a continuous variable as well. Pearson's correlation revealed a statistically significant negative correlation between the validity effects and the age; the older the child, the smaller the effects; $r(83) = -.319$, $p = .003$.

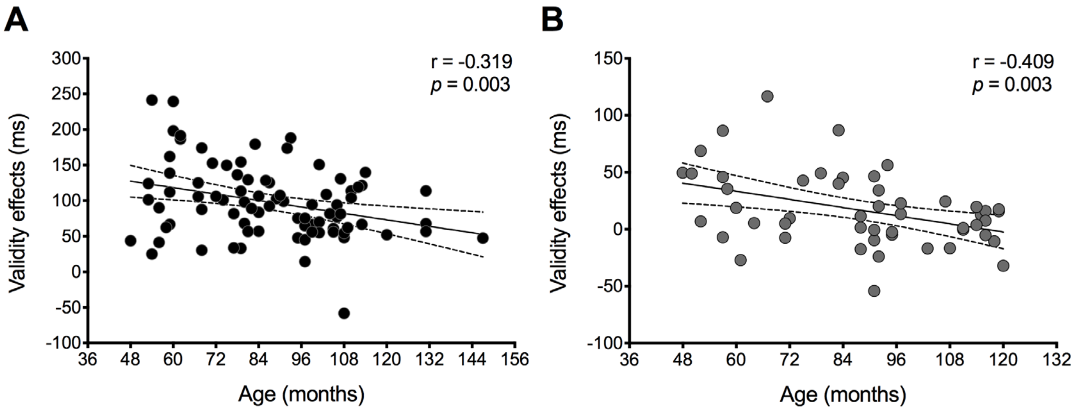

Figure 3. Scatterplot of the correlation between the validity effects (in ms) and children's age (in months) in **A)** Experiment 1 (block design) and in **B)** Experiment 2 (trial-by-trial design). In both experiments, the significant negative relationship indicated that the magnitude of the validity effects decreased linearly as a function of age.

Source of the temporal orienting effects

To analyse the source of the variability in the magnitude of the temporal orienting effects, we first standardized the data per age group to avoid the potential confound of age**.** Pearson's correlation coefficient was. Using Bonferroni correction, a significant positive correlation between the magnitude of the effects and the Invalid condition, $r(109) = .441$, $p < .001$ (Figure 4A), and a significant negative correlation between the magnitude of the effects and RTs in the Valid condition were observed, $r(109) = -.237$, $p = .013$ (Figure 4B). This indicated that greater validity effects were associated to slower responses in invalid (unexpected) trials and to faster responses in valid trials.

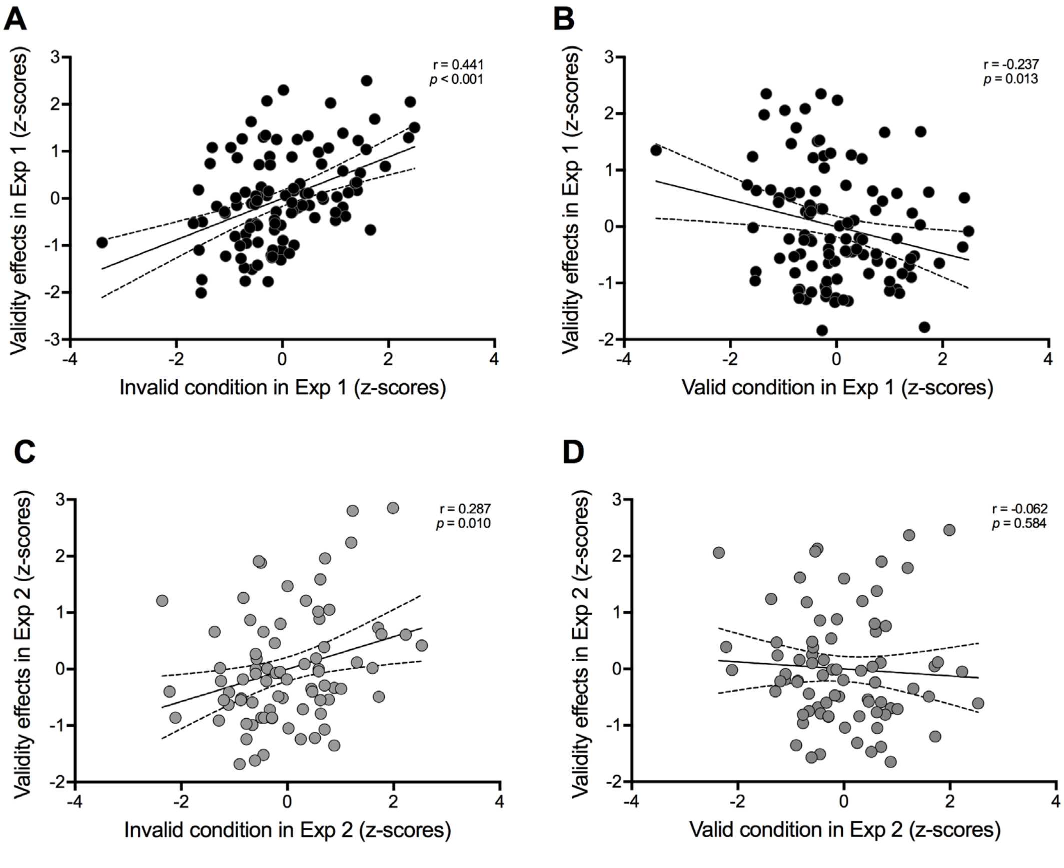

Figure 4. A) Scatterplot of the correlation between the standardized validity effects (VE) and the standardized reaction times (RT) in the invalid (left) and valid (right) condition in the Experiment 1 (block design). **B)** Scatterplot of the correlation between the standardized VE and standardized RT in the invalid (left) and valid (right) in the Experiment 2 (trial-by-trial design). All Z-scores were computed for raw scores for each age data set.

Sequential effects

To test the potential exogenous effects in temporal orienting due to the high number of same-trial repetitions in a block design, we analysed the presence of sequential effects (i.e., the repetition of a previous-short SOA compared to a previous-long SOA). There was a main effect of previous SOA [$F(1, 103) = 23.2$, $p < .001$, $\eta_p^2 = .18$], due to participants' shorter RTs in previous-short trials ($M = 326$, $SD = 66$) compared to previous-long trials ($M = 355$, $SD = 92$). Critically, no significant previous SOA by Age interaction [$F(2, 103) = 2.32$, $p = .10$] was found. This indicates that all groups were equally affected by sequential effects. An additional analysis was carried out to further investigate the age distribution of the sequential effects in children. Pearson's correlation revealed a non-statistically significant correlation between the age (calculated in months) and the sequential effects ($r(83) = .105$, $p = .345$), further suggesting that children's age did not modulate automatic sequential effects.

Taken together, these results reveal that in an experimental design with invalid trials, controlling for spatial predictability, younger children (4-7 years) were able to use temporal cues to orient attention in time endogenously. Moreover, a developmental progression was observed with greater validity effects in the younger group compared to the older group of children (8-12 years), and in the older group compared to the adult group. Although automatic sequential effects were observed, they affected all age groups equally. The results also show that the magnitude of the temporal orienting effects is positively correlated with performance in the invalid (unexpected) conditions, with those participants showing greater effects responding slower in the unexpected temporal condition.

In Experiment 1 we used a block design, which intrinsically contains a high number of same-trial presentations. Experiment 2 aimed to replicate and extend the results of the first experiment by manipulating the temporal expectations on a trial-by-trial basis to minimize automatic sequential effects on temporal orienting abilities.

Experiment 2: Trial-by-trial design

Method

Participants

Ninety-two participants were tested. None of the participants in Experiment 1 were enrolled in Experiment 2. Twelve participants were excluded for exceeding 2 *SD* from the group mean accuracy ($n = 4$) or exceeding 2 *SD* from the group mean RT ($n = 5$), not finishing the experiment (n = 1), not following task instructions by pressing constantly throughout the trial (n = 1), or technical error (n = 1). The final sample of 80 participants was divided into a group of thirty-three children younger than 8 years of age (4- to 7-year-old), a group of eighteen children aged 8 years or older (8- to 12-year-old), and a group of twenty-nine adults. Demographic characteristics of each group are reported in Table 2. A more detailed description of the demographic characteristics within each age group are reported in the Appendix. All participants were tested by the same experimenter. All participants had normal or corrected-to-normal vision, no auditory problems, and no language development disabilities. Ethical approval of the protocol was obtained from the University of XX, in accordance with the 1964 Declaration of Helsinki. Parents provided written informed consent prior to each child's participation in the study.

Table 2. Main demographic characteristics of the participants in Experiment 2 (trial-by-trial design).

		Age		**Gender**		**Handedness**	
	n	**Mean (SD)**	**Range**	**Female**	**Male**	**Left**	**Right**
4-7 years	33	6.2 (1.3)	4.0 – 7.9	16	17	5	28
8-12 years	18	9.3 (0.6)	8.1 – 10.0	10	8	2	16
Adults	29	21 (1.2)	18 – 28	25	4	2	27

Age in years. Standard Deviation (SD) in parenthesis

Stimuli and procedure

The same procedure was used as in Experiment 1, with two differences: (i) instead of a block design, a trial-by-trial design was used, and (ii) the order constraints were removed—trials were presented in random order instead of pseudo-randomly. The experiment was also divided into two identical blocks with a short break of approximately 2 min between them. The same number of stimuli from each condition was included in each block.

Results

Mean RTs for each condition and participant were obtained. Omissions, anticipated responses (within the cue and 100 ms after target onset), and delayed responses (1500 ms after target onset) were considered errors and excluded from analysis (Mento & Tarantino, 2015). Trials with RTs exceeding 2 *SD* from the individual average were excluded. The remaining responses were considered correct (Mento & Tarantino, 2015).

Age effects in temporal orienting

To determine the validity effect at the short interval, an ANOVA involving Validity (Valid, Invalid) and Age (4-7yo, 8-12yo, adults) was performed. As in Experiment 1, a significant Validity effect [$F(1, 77) = 13.80$, $p < .001$, $\eta_p^2 = .15$] and a Validity by Age interaction [$F(1, 77) = 4.96$, $p = .009$, $\eta_p^2 = .11$] were found (see Figure 3A). This interaction was broken down by Age. A significant difference between valid and invalid conditions was found in the younger group (4-7y), due to children's faster RTs to valid ($M = 429$, $SD = 90$) than invalid trials ($M = 453$, $SD = 92$), $t(32) = 3.682$, $p = .001$, $d = 0.64$. Adults also responded faster to valid ($M = 282$, $SD = 37$) than invalid trials ($M = 289$, $SD = 40$), $t(28) = 2.84$, $p = .008$, $d = 0.53$. As in Experiment 1, the young group of children showed a greater magnitude of effects ($M = 24$, $SD = 37$) compared to adults ($M = 6$, $SD = 12$), $t(60) = 2.43$, $p = .014$, $d = 0.63$. Thus, the results concerning these two groups replicated the results of Experiment 1. The use of a trial-by-trial design in Experiment 2 revealed no significant effects in the older group of children (8-12y), given the similar responses to valid ($M = 323$, $SD = 45$) and invalid trials ($M = 327$, $SD = 44$), $t(17) = .95$, $p = .36$. While these results do not replicate those found in Experiment 1, which used a block design, they do replicate previous null findings in the group of children aged 11 years old using the same trial-by-trial design (Johnson et al. 2015, and Experiment 1 in Johnson et al. 2016).

Developmental trend of temporal orienting effects.

As in Experiment 1, Pearson's correlation again revealed a statistically significant negative correlation between the validity effects and the age in the second experiment; the older the child, the smaller the effects; $r(51) = -.409$, $p = .003$. Overall, the results reiterate the previous findings obtained in the ANOVA, revealing that the magnitude of the validity effects varies with age such that children show the greatest amount of effects early in childhood.

Source of the temporal orienting effects

As in Experiment 1, to analyse the source of the variability in the magnitude of the temporal orienting effects we first standardized the data per age group to avoid the potential confound of age. Using Bonferroni correction, a significant positive correlation between the magnitude of the effects and RTs in the Invalid condition, $r(80) = .287$, $p = .010$ (Figure 4C) was found, but no correlation between the magnitude of the validity effects and Valid condition, $r(80) = -.062$, $p = .584$ emerged (Figure 4D). This result indicates that greater temporal orienting effects were associated with slower RTs in the invalid (unexpected) condition.

Sequential effects. Post-hoc analyses were carried out to determine the sequential effects (i.e., the repetition of a previous short SOA vs. a previous long SOA). As in Experiment

1, there was a main effect of previous SOA [$F(1, 77) = 5.39$, $p = .02$, $\eta_p^2 = .065$], but no previous SOA by Age interaction was observed [$F(2, 77) = .27$, $p = .77$]. Again, the results indicate that all groups were equally affected by automatic sequential effects. An additional analysis was carried out to further investigate the age distribution of the sequential effects in children. Pearson's correlation revealed a non-statistically significant correlation between the age (calculated in months) and the sequential effects ($r(83) = -.120$, $p = .401$), further suggesting that children's age did not modulate automatic sequential effects.

Taken together, the results from Experiment 2 confirmed that in an experimental design with invalid trials, and controlling for spatial predictability, young children (4-7 years) were able to use temporal cues to orient attention in time endogenously. Moreover, a developmental progression was observed with greater validity effects in the younger group compared to adults. No significant effects were observed in the older group of children (8-12 years), replicating previous studies using a validity design (Johnson et al., 2015; Experiment 1 in Johnson et al., 2016). Although automatic sequential effects were observed, they affected all age groups equally. The results also show that the magnitude of the temporal orienting effects positively correlated with the performance in the invalid (unexpected) conditions, with those participants showing greater effects responding slower in the unexpected temporal condition.

Comparison between experiments (Block vs Trial-by-trial design).

In order to directly compare maximizing (Experiment 1) and minimizing (Experiment 2) automatic sequential effects on temporal orienting abilities, we compared the validity effects in the two experiments. A mixed ANOVA with Experiment (Exp. 1, Exp. 2), Age (4-7yo, 8-12yo, adults) as between-subject factors, and Validity (Valid, Invalid) as within-subjects factor, revealed a significant main effect of Experiment [$F(1, 183) = 11.26$, $p = .001$, $\eta_p^2 = .058$]. Quite unexpectedly, participants responded faster in Experiment 2 than in Experiment 1. No Age by Experiment interaction was observed [$F(1, 183) = 1.69$, $p = .19$]. There was also a main effect of Validity [$F(1,183) = 258$, $p < .001$, $\eta_p^2 = .59$] and a Validity by Age interaction [$F(2, 183) = 16.6$, $p < .001$, $\eta_p^2 = .15$]. Interestingly, a statistically significant Validity by Experiment interaction [$F(1, 183) = 150$, $p < .001$, $\eta_p^2 = .45$] was found, due to smaller effects in Experiment 2 ($M = 12$; $SD = 27$) compared to Experiment 1 ($M = 88$; $SD = 50$). A significant Validity by Experiment by Age interaction

[F(2, 183) = 3.78, p = .025, η_p^2 = .040] was also found. This interaction was then broken down by Age.

In the younger group (4-7y), we observed a significant Validity by Experiment interaction (F(1,81) = 69.75, p < .001, η_p^2 = .463). A significant difference in invalid trials between experiments was found (t(81) = 2.906, p = .005, d = .64), due to participants' faster RTs in Experiment 2 (M = 453, SD = 92) compared to Experiment 1 (M = 508, SD = 79). The opposite pattern of results was observed in the valid condition, in which participants showed faster RTs in Experiment 1 (M = 396, SD = 66) compared to Experiment 2 (M = 430, SD = 90) (t(81) = 1.95, p = .054, d = 0.43).

In the older group of children (8-12y), we observed a significant Validity by Experiment interaction (F(1,49) = 54.62, p < .001, η_p^2 = .527). As found in the young group, a significant difference between experiments arose in the invalid condition [t(49) = 5.650, p < .001, d = 1.6], with participants being faster in Experiment 2 (M = 327, SD = 44) compared to Experiment 1 (M = 415, SD = 57). However, no significant difference in valid trials was observed [t(49) = 1.04, p = .30].

The same results were found in adults. That is, there was a significant Validity by Experiment interaction (F(1,53) = 69.84, p < .001, η_p^2 = .569) due to a difference between experiments in invalid trials [t(53) = 4.808, p < .001, d = 1.32] driven by participants' faster RTs in Experiment 2 (M = 289, SD = 40), compared to Experiment 1 (M = 347, SD = 49), but there were no significant differences in valid trials [t(53) = .51, p = .61].

Overall, all three groups of participants responded faster in Experiment 2 compared to Experiment 1 in the invalid (unexpected) condition, but no significant differences were observed in the valid condition. This suggests that the trial-by-trial design promoted faster RTs in the invalid (unexpected) trials.

The analysis of the sequential effects comparing the two experiments in an ANOVA showed that the main effect of previous SOA was significant [F(1,183) = 23.98, p < .001, η_p^2 = .12]. Also, a marginal Experiment by previous SOA interaction was observed [F(1, 183) = 3.36, p = .068], due to greater effects of previous SOA in Experiment 1 than Experiment 2. Finally, the Age by previous SOA interaction [F(2, 183) = 2.04, p = .13] and the Age by Experiment by Previous SOA interaction were not significant [F(2, 183) = .697, p = .50], suggesting that the sequential effects were comparable across ages.

Discussion

In the present research we investigated whether the presence of expectancy violations in a temporal orienting design could reconcile the existing contradictory evidence on the developmental trajectory of endogenous temporal orienting of attention. To do so, we tested three age groups in a temporal orienting task that included invalid (unexpected) trials, and we controlled for spatial predictability presenting cues and target in the central location. We sought to establish whether developmental differences would arise in the context of expectancy violations, and whether the source of the temporal orienting differences derived from the condition that violated the temporal expectancy given the cue (i.e. invalid condition). To this end, the group of young children was selected to be comparable to the group of young children tested in the Mento & Tarantino (2015) and Mento et al., 2019 studies, and an older group was selected to be comparable to the children tested in the studies by Johnson and colleagues (2015, 2016). In Experiments 1 and 2 we used a blocked and a trial-by-trial design, respectively, to vary the weight of exogenous sequential effects. The results indicate that in both experiments younger children (4-7-year-olds) show greater temporal orienting effects compared to older children (8-12-year-olds) and adults, highlighting a developmental trajectory. We observed that with increased age, children and adults are better prepared (i.e., display faster reaction times) in the invalid condition leading to a reduction in validity effects. Indeed, our results revealed that temporal orienting effects positively correlated with performance in the invalid (unexpected) condition in both experiments. Moreover, when a block design was used, temporal orienting effects were negative correlated with performance in the valid (highly predictive) condition. This finding is expected in this type of block design with a higher number of consecutive valid trials. In the group of older children, the improved performance in invalid trials implies an absence of validity effects in Experiment 2 when temporal orienting effects are not boosted by sequential effects as in Experiment 1. The whole pattern of results replicates previous research providing an explanation for the source of the apparently contradictory findings.

Children's ability to orient attention in time endogenously

Taken together, our results reveal that children can orient attention in time endogenously. This conclusion is drawn from the significant difference between valid and invalid trials in the younger group of children, which were replicated in both experiments. These findings converge with Mento and colleagues' findings (Mento & Tarantino, 2015; Mento & Vallesi, 2016; Mento et al., 2019), revealing that young children are able to orient attention in time endogenously to benefit behavior even when exogenous effects are kept to a minimum. The results from our groups of young children replicate the finding that this ability is observed in children as young as 4 years of age (Mento & Tarantino, 2015; Mento et al., 2019). This is consistent with the infant findings showing that endogenous temporal orienting abilities can already be observed in the second year of life (Martinez-Alvarez et al., 2017).

Interestingly, the current study also replicated the results from Johnson and colleagues (2015; 2016). Temporal orienting effects were observed in the group of older children (8 to 12 years) only in the design in which validity effects were boosted by exogenous effects using a blocked design (Experiment 1), but not when these exogenous effects were reduced by using a trial-by-trial presentation (Experiment 2). This pattern replicates the absence of temporal orienting effects previously observed in 11-year-olds in the absence of exogenous cues. Certainly, the ways in which exogenous effects were manipulated in the Johnson et al. study (2016) and in our study were different. While we used sequential effects, Johnson et al. (2016) used the repetition of the same temporal interval with repeated cue presentation. However, both exogenous effects were as effective in boosting validity effects. Critically, we observed that those effects affected all age groups equally, ruling out the possibility of them being the source of the differences between groups.

Importantly, the fact that no validity effects are observed when using a validity paradigm may be due (at least) to two reasons. First, and most obvious, it could be due to participants being unable to benefit from the temporal (valid) cue. Second, it is possible that participants could be equally well-prepared to respond in the invalid (less predictive) condition than in the valid (highly predictive) condition. Although in both scenarios we would not observe a difference in performance between valid and invalid conditions (i.e. a null effect), the interpretation in terms of temporal orienting abilities in children (being either present of absent) is fundamentally different. The older group of children (mean age 11 years) tested in Johnson et al. (2015) showed a null effect, which the authors interpreted as an indication of children's *inability* to use a temporal cue to endogenously orient attention in time. Using a similar validity paradigm, our older children group (aged 8 to 12) in Experiment 2 also show a null effect. Importantly, our findings indicate that younger children group (aged 4 to 7) are indeed *able* to use a temporal cue endogenously. Because our younger children group can indeed orient in time, we interpret the null finding of the older group not as an absence of a temporal orienting abilities in children, but to a flexible ability to orient in time to less predictable situations as a function of executive control development. In the case of Johnson et al.'s (2015) null effect, both possibilities still remain possible due to (at least) two methodological aspects. First, the experimenters manipulated spatial and temporal orienting in the same task, which could tap into general cognitive load required to successfully perform the task. Second, the stimuli used as temporal cues were not child-friendly and not semantically transparent, which could have introduced additional working memory load in order to encode, maintain and retrieve the information provided by the cue. Therefore, it is possible that potential confounds such as cue transparency, child-friendly task, and overall higher working load could be responsible for children's inability to use the temporal cue. However, it is still plausible that even in this higher working load paradigm children were indeed able to use the temporal cue and, additionally, able to also adapt to the invalid (less predictive) condition. We find this second possibility unlikely, due to the above-mentioned methodological challenges children were presented with, but still theoretically plausible.

Therefore, regarding the presence (or absence) of endogenous temporal orienting mechanisms in children, the results obtained and replicated in both experiments clearly show that the younger group of children demonstrate temporal orienting abilities. That is, young children can orient attention in time irrespective of the way temporal expectancies are presented, either blocked or in a trial by trial basis. We argue that the result obtained in older children reflects an age-related shift in the way expectancy violations are processed, as will be discussed below.

Developmental course of endogenously temporal orienting

In both experiments, results revealed developmental differences between age groups, with younger children differing from older children and adults in their ability to orient attention in time. This conclusion is drawn from the significant difference in validity effects between the younger group of children (4 to 7 years) and the older group (8 to 12 years), as well as between young children and adults. These results were replicated in both Experiment 1 and 2. Because previous studies showed inconsistent findings regarding the developmental trajectory of endogenous temporal orienting abilities, our results may help elucidate a potential source of discrepancy.

While replicating the existence of endogenous temporal orienting effects in children, our results seem to contradict previous studies showing no age differences when comparing temporal orienting abilities in children of varying ages (Mento & Tarantino, 2015). However, we propose that the explanation for these differences derives from the involvement of conflict due to the presence of expectancy violations. Briefly stated, in those temporal orienting studies that use only 100% predictive cues, the temporal expectancies are *never* violated. Hence, no conflict is introduced in the design and, as a consequence, no age effects are observed (Mento & Tarantino, 2015). In contrast, in the presence of invalid trials, the predictability of the temporal cue with respect to the actual target time *is* violated. And because the presence of such violations of expectancy taps into executive components of attention (Conejero & Rueda, 2017), which develop progressively over childhood, developmental differences arise.

Our results replicate previous results on age differences (Johnson et al., 2016), not only with respect to developmental changes when comparing children and adults, but, more importantly, in terms of directionality: the older the participant, the *smaller* the magnitude of the temporal orienting effects. In both Experiments 1 and 2 we found that younger children show *greater* temporal orienting effects compared to older children and adults. We do not interpret this to indicate children showing better orienting abilities compared to adults. Rather, we propose that young children have more difficulties in dealing with conflict due to a more immature executive control system. Specifically, when temporal orienting mechanisms are assessed using invalid trials, children may need to recruit not only their attentional orienting network but also executive attention, because they need to flexibly adapt to this conflict. Because the executive network shows a progressive development course across childhood (Pozuelos et al., 2014; Rueda, Fan, et al., 2004; Rueda, Posner, Rothbart, & Davis-Stober, 2004), developmental differences arise. Thus, the observed age differences may not be an index of temporal orienting abilities *per se*, but rather an indication of a developmental change in the way children flexibly adapt to expectancy violations, and become progressively better prepared in those trials involving conflict (i.e., invalid trials).

This interpretation is sustained by the fact that participants' performance is associated with the invalid condition exclusively. The reduction in the validity effects with development was specifically related to invalid trials. These results were replicated in both Experiments 1 and 2. Crucially, the direction of the correlations indicates that smaller validity effects relate to better preparation (faster reaction times) for an invalid (unexpected) time. These results suggest that the decrease in validity effects is due to children being progressively faster in invalid (unexpected) trials. In addition, these effects cannot be due to sequential effects since these did not differ between the age groups.

Therefore, we interpret the reduction in validity effects with age as an index of *better* adaptation to the invalid (unexpected) condition. This interpretation is in agreement with the evidence coming from previous developmental studies on attention in the visuo-spatial domain (Pozuelos et al., 2014; Rueda, Fan, et al., 2004). In these studies, comparable orienting effects are observed in 6- and 10-year-old children when the design does not involve conflict. However, when conflict is introduced, developmental differences in orienting arise between 6 and 12 years of age (Pozuelos et al., 2014).

In terms of the underlying mechanisms, we suggest that previous studies on temporal orienting may have tapped into different attentional components—either orienting mechanisms alone, in the absence of expectancy violations (Martinez-Alvarez et al., 2017; Mento & Tarantino, 2015; Mento & Vallesi, 2016; Mento et al., 2019), or orienting mechanisms affected by executive control mechanisms when expectancy violations are present (Johnson et al., 2016, 2015).

Based on this, we propose a distinction between *rigid* and *flexible* temporal orienting mechanisms. *Rigid* temporal orienting may be observed when a fixed temporal expectation is built and used. Developmentally, rigid temporal orienting may already be observed at the age of 2 years (Martinez-Alvarez et al., 2017) and appears to remain stable from 6 years of life through adulthood (Mento & Tarantino, 2015). In contrast, *flexible* temporal orienting might be observed when temporal expectations are violated and, hence, executive mechanisms, which develop progressively over childhood, are required.

The current findings open new perspectives on the interaction between the orienting and executive attention networks, suggesting future work investigating the interaction of the three networks in the temporal domain. In this line, previous studies on visuo-spatial attention have observed an interaction between the orienting and executive systems in adulthood (Callejas, Lupiáñez, & Tudela, 2004; Fan, McCandliss, Sommer, Raz, & Posner, 2002) and childhood (Johnson et al., 2019; Mezzacappa, 2004; Mullane, Lawrence, & Corkum, 2014; Pozuelos et al., 2014). Unfortunately, this interaction has not yet been investigated in the temporal orienting domain. Future research should be undertaken to adapt the Attention Network Test (ANT) to the temporal domain and directly examine the interaction of the orienting and executive networks in the presence of temporal expectancy violations.

Finally, the temporal orienting processes investigated here may have an adaptive value for the developmental trajectory of other cognitive domains with intrinsic temporal characteristics, such as language and music (Astheimer, Janus, Moreno, & Bialystok, 2014; François, Chobert, Besson, & Schön, 2013). Thus, an important domain for further exploration concerns whether the temporal orienting abilities investigated here may be a part of essential aspects of cognitive development that involve temporal processing, such as language (de Diego-Balaguer, Martinez-Alvarez, & Pons, 2016).

Conclusions

In a study with three age groups (younger children aged 4 to 7 years, older children aged 8 to 12 years, and young adults) assessing participants in a block design (Experiment 1) and a trial-by-trial design (Experiment 2), we show that even the youngest children are able to use temporal predictions to orient attention in time endogenously. These results provide evidence that, with progressive development, age differences in endogenous temporal orienting abilities are observed due to improved capacity to deal with conditions that involve violations of expectancy (i.e., invalid trials). When taking this factor into consideration, seemingly contradictory findings seem to converge.

CRediT authorship contribution statement

Anna Martinez-Alvarez: Conceptualization, Data curation, Formal analysis, Investigation, Method- ology, Project administration, Software, Visualization, Writing - original draft, Writing - review & edit- ing. **Monica Sanz-Torrent**: Methodology, Resources, Validation. **Ferran Pons**: Conceptualization, Methodology, Validation, Writing - review & editing. **Ruth de Diego-Balaguer**: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing - review & editing.

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APPENDIX

Detailed demographic characteristics of the participants included in Experiment 1 (block design) and Experiment 2 (trial-by-trial design)

			Age		Gender		Handedness	
		n	Mean (SD)	Range	Female	Male	Left	Right
Exp.1	4-5 years	22	5.0 (0.5)	4.0 – 5.9	9	13	1	21
	6-7 years	28	6.9 (0.5)	6.0 – 7.9	10	18	4	24
	8-9 years	28	8.5 (0.4)	8.1 – 9.5	10	18	1	27
	10-12 years	5	11.0 (0.8)	10.0 – 12.2	1	4	1	4
	Adults	26	20 (1.3)	18 – 30	21	5	0	26
Exp.2	4-5 years	14	4.9 (0.6)	4.0 – 5.9	5	9	3	11
	6-7 years	19	7.3 (0.6)	6.0 – 7.9	11	8	2	17
	8-9 years	17	9.3 (0.6)	8.1 – 9.9	10	7	2	15
	10 years	1	10.0	10.0	0	1	0	1
	Adults	29	21 (1.2)	18 – 28	25	4	2	27

Age in years. Standard Deviation (SD) in parenthesis. Dotted lines separate the three age-groups included in the analyses.

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