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Running head: TIME DISTRACTION CAUSED BY A DISTRACTOR

Time contraction caused by a distractor  
in children and adults: the influence of inhibition capacities

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**Highlights:**

- Distractor trials are perceived shorter than trials showing no distractor.
- The time contraction caused by the distractor decreases with age but the effect is mediated by, and only by, inhibition scores.
- The interference remains constant for both ranges of durations.
- These results draw the existence of an attention-control mechanism in time perception.

### **Abstract**

The aim of this study was to examine the cognitive processes involved in time contraction caused by a non-temporal distractor during the presentation of a temporal stimulus. To this aim 95 children aged 5 to 8 years old as well as 25 adults were first trained to discriminate, on two visual temporal bisection tasks, a short standard duration (400 or 600ms) from a long one (1500 or 2400ms). They had then to decide whether intermediate stimulus duration was more similar to the short or to the long standard duration. Furthermore, a distractor with a duration of 40ms and taking the form of a 4cm diameter rosette, either did or did not appear during the temporal stimulus. Participants' task was to report whether they had been exposed to the short or long standard duration. Subsequently, each subject's capacities in terms of memory skills (short term and working memory), as well as attention (selective attention and inhibition), were assessed using different neuropsychological tests. The results showed a shortening effect of the perceived time from non-distractor to distractor trials, which also turned out to attenuate with the age increase. Interestingly, inhibition was found to mediate this effect while the other cognitive variables were found to be of no significance. We therefore discussed the importance of categorizing two attentional interferences: one related to attention control and the other to attentional resources.

**Keywords:** Development, Time Perception, Temporal Bisection, Inhibition.

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Have you ever noticed how time flies when we prepare a cake's dough compared to its cooking time? This is not a bias caused by gluttony. In fact, when preparing the cake's dough we have to perform several actions, thus we reduce our available resources to process time. In the other situation, all our resources are available to us, as we can only wait to taste what we have cooked and observe the masterpiece from the other side of an oven glass. The dual-task paradigm has been specifically designed to investigate this effect. In a typical dual-task procedure, participants have to perform a temporal task alone and along with a non-temporal task. The typical result is an underestimation of the perceived time within the non-temporal task compared to the single temporal task (for a review see Block, Hancock & Zakay, 2010; Brown, 1997; Brown, Collier & Night, 2013). The aim of the present paper is to further investigate the effects non-temporal information can have on time judgment in children even when the temporal information does not need to be processed.

The classic shortening effect obtained in the dual-task paradigm has mainly been explained through the attentional resources allocated to time. In other words, the more attentional resources the processing of non-temporal information requires during the estimation of a stimulus duration, the shorter the stimulus duration is judged to be (Casini & Macar, 1997; Coull, Vidal, Nazarian & Macar, 2004; Fortin & Couture, 2002; Gaudreault, Fortin, & Macar, 2010; Hallez & Droit-Volet, 2017, 2019; Kladoyopoulos, Hemmes & Brown, 2004). To explain this phenomenon researchers stated that this shortening estimation of time resulted from a sharing process within a pool of limited attentional resources for both temporal and non-temporal tasks (Block et al., 2010; Thomas & Weaver, 1975; Zakay, 1989, 1992, 1993).

This hypothesis also fits well with actual internal clock models. As stated by some authors (Church, 1984; Gibbon, Church & Meck, 1984, Zakay & Block, 1996, 1998) we all are intrinsically equipped with an internal clock, consisting of a pacemaker, an attention-controlled switch and an accumulator. A pacemaker would generate a continuous flow of pulses (temporal units) transferred into the accumulator through an attention-controlled switch. In other words, the more pulses stored within the accumulator, the longer the subjective time as more pulses are stored within the accumulator. The switch component opens or closes at the beginning and at the end of a stimulus to be timed. Nonetheless, it can also open during the appearance of a temporal stimulus if there is not enough attention dedicated to time processing to keep it closed.

Thereby, the longer the switch is closed, the less time is underestimated as fewer units are lost during the timing process. Zakay and Block (1996, 1998) have added to this clock system a second attentional mechanism called “attentional gate” that controls the amount of attentional resources allocated to time processing. The opening of the attentional gate would thus be smaller in a condition of a dual-task compared to the single-task, thereby limiting the number of pulses passing into the accumulator. However, these authors remain unclear about the terms of attention and whether these two mechanisms tap into different aspects of attention.

In line with the data collected with an adult sample, studies conducted on children also showed a contraction of the reproduced duration with the presence of a non-temporal-task compared to a single temporal task. Of interest to us, developmental studies have also revealed age-related differences in temporal performance with a greater interference (i.e., less accurate and more variable productions) in younger children than in older ones (Chelonis, Flake, Baldwin, Blake, & Paule, 2004; Crowder & Hohle, 1970; Droit-Volet, 1999; Droit-Volet & Rattat, 1999; Espinosa-Fernandez, de la Torre Vacas, del Rosario Garcia-Viedma, Garcia-Gutierrez & Colmenero 2004; Espinosa-Fernandez, Miro, Cano, & Buela-Casal, 2003; Gautier & Droit-Volet 2002; Matsuda & Matsuda, 1983; Rattat & Droit-Volet, 2007; Rattat, 2010). This has therefore been explained by an increase of attentional resources during the development of children, which is also closely linked to the development of their prefrontal cortex (Gathercole, 2002; Towse, Hitch & Horton, 2007). Recent studies indeed showed a correlation between the linear reduction of the interference caused by the single/dual task difference and the increasing selective attention, thus explaining younger children’s less developed abilities to deal with time (Hallez & Droit-Volet, 2017, 2019).

Nonetheless, only a small number of studies focused on the effect of a non-temporal stimulus that does not need to be processed (i.e., that is task-irrelevant) within samples of typically developing children. Zakay (1992), who examined children aged 7 to 9 years old, already reported a decrease in children’s temporal reproduction when a distractor (e.g., a jumping frog) appeared during the trial. Zakay thus concluded that children’s time processing is similar to that of adults. Nevertheless, Gautier and Droit-Volet later showed that the role of attention within such a distractor paradigm is less clear in younger children. Indeed, the authors reported a counterintuitive effect where diverting attention away from duration in a temporal bisection task shifted the bisection points towards the left for 5-year-olds (indicating an overestimation of time caused by the distractor), and towards the right for 8-year-olds (indicating an underestimation of time caused by the distractor). Authors thus proposed a possible distinction between an attentional resource-based interference and an attentional-

control based interference which would be linked to inhibition skills (Gautier & Droit-Volet, 2002). In other words, if a child does not have the ability to get rid of stimuli that are irrelevant to the task (e.g., lack of inhibition) then he automatically treats additional information that interferes with his performance. This would be totally in line with numerous studies showing that young children find it difficult to inhibit irrelevant behaviors that are automatically triggered by the context and to resist attentional distractors (Arlin, 1986a, 1986b; Droit-Volet, 2003, 2010; Droit-Volet, de Lurdes Delgado, & Rattat, 2006; Hallez, Damsma, Rhodes, van Rijn, Droit-Volet, 2019; Smith, Taylor, Rogers, Newman, & Rubia, 2002; Zakay, 1992).

Nonetheless this result is a paradox as inhibition is a late process to mature (Dempster & Brainerd, 1995; Diamond, 2002; Fuster, 2015). One might therefore wonder why the youngest children did not generate a greater time underestimation than their older peers. The overly complex nature of the distractor used by Droit-Volet & Gautier, changing form every 250ms, could have forced the youngest ones to base their estimates on the commonly used rule of “more of... equals more time” (Levin, 1992). Thereby, the lengthening effect observed within the 5 year-olds may be attributable to the complex choice of the distractor. Nonetheless, this does not refute the proposal of a double attentional interference: i) one based on resources and related to selective attention (as previously shown in the literature (Hallez & Droit-Volet, 2017, 2019)) and ii) the other one on attentional control and inhibition skills.

In order to detect this second kind of interference, children from 5 to 8 years old as well as adults were confronted to a temporal visual bisection task, with or without a distractor. Participants also performed neuropsychological tests allowing us to gain inhibition, selective attention, short-term memory and working memory scores, with the final goal to prove the explanatory superiority of the inhibition factor above others. As in Gautier and Droit-Volet (2002) the temporal bisection task was used for two reasons. First, because it is the easiest temporal task that exists to date (Droit-Volet, 2016). Its simplicity should therefore make it possible to detect the interference linked to inhibition without bringing out the second source of interference linked to attentional resources. Second, because temporal answers are done orally in this task and does not involve the motor component, which, as we know, greatly interferes with the temporal child's judgment (Droit-Volet, 2010; Droit-Volet, Wearden & Zélanti, 2015; Fox, Henderson, Marshall, Nichols, & Ghera, 2005; Hallez et al., 2019; Karaminis et al., 2016; Klenberg, Korkman, & Lahti-Nuutila, 2001; Szelag, Kowalska, Rymarczyk & Pöppel, 2002). The time lengths used in our study were less than or equal to 2.5 seconds. Those short durations have been proposed to further rely on inhibition capacities (Droit-Volet, 2010). Finally, the children's age range from 5 to 8 years was selected because it

usually shows a high cognitive abilities' heterogeneity (Flavell, 1982), which is related to brain development (Casey, Tottenham, Liston & Durston, 2005; Lenroot & Giedd, 2006). Our assumptions were therefore that (1) participants should produce an age-related time contraction from non-distractor to distractor trial that should decrease with age, and (2) that this effect should be mediated with individual inhibition capacities, while (3) the other neuropsychological scores should not show any direct effect on the temporal contraction from non-distractor to distractor trials, or at most, to a lesser extent than inhibition.

## Method

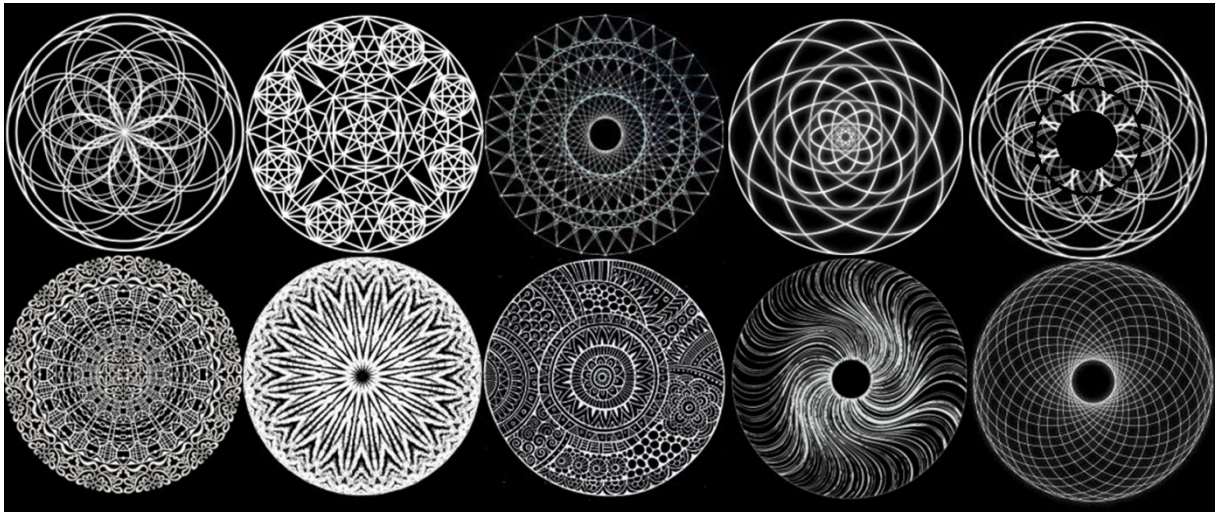
### Participants

A total of 120 participants constituted our experimental sample: twenty 5-year-olds (10 girls and 10 boys; mean age = 5.58 years,  $SD = 0.25$ ), twenty-five 6-year-olds (13 girls and 12 boys; mean age = 6.42 years,  $SD = 0.25$ ), twenty-four 7-year-olds (10 girls and 14 boys; mean age = 7.50 years,  $SD = 0.33$ ) twenty-six 8-year-olds (16 girls and 10 boys; mean age = 7.74,  $SD = 0.26$ ), as well as twenty-five adults (21 females and 4 males; mean age = 20.70 years,  $SD = 1.83$ ). The children were recruited from different nurseries and primary schools, all located in the department of Puy de Dôme, France. The adults were undergraduate Psychology students at the University of Clermont Auvergne. The children's legal guardians, as well as adult subjects, signed written informed consent forms for their participation in this experiment. This investigation was carried out according to the principles of the Helsinki declaration and was approved by the IRB-UCA research ethical committee.

### Material

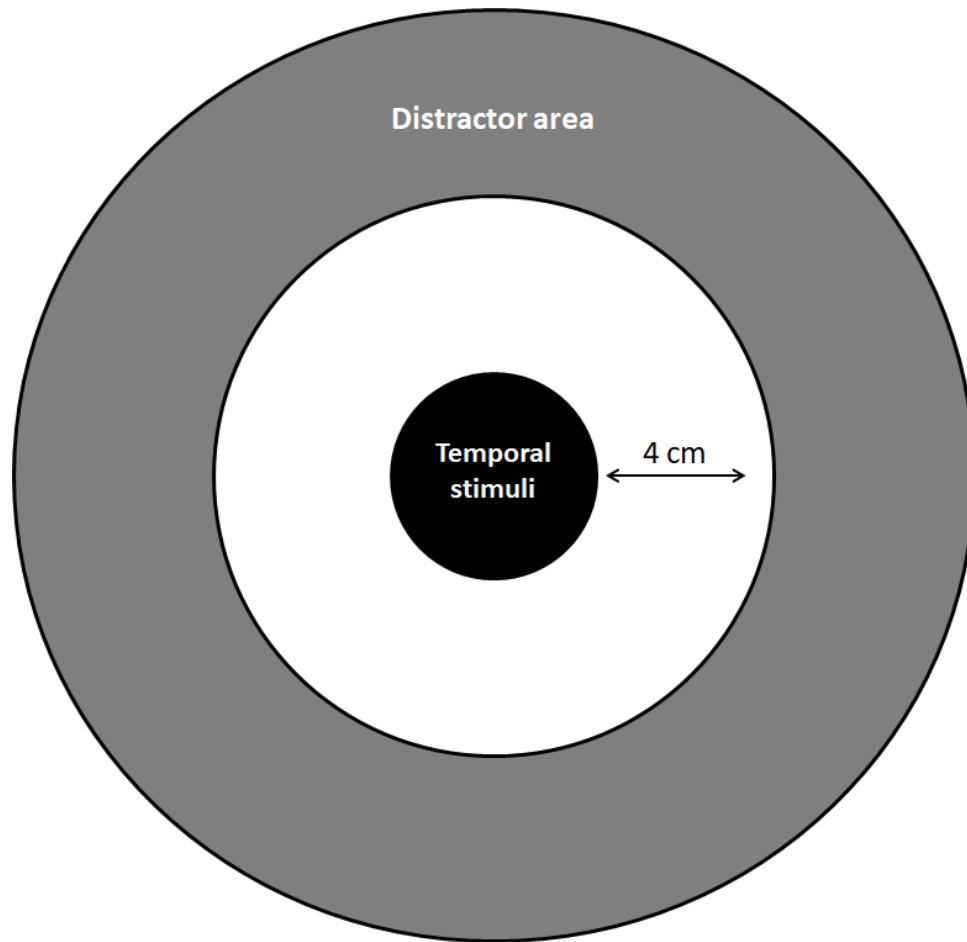
In a quiet and neutral room in their schools or university, participants were individually tested using a computer balinea o.book 5,1. Experimental events and data recording were controlled by E-prime 2.1 software (Psychology Software Tools, Pittsburgh). The stimulus used for the bisection task was a blue filled circle, measuring 4.5 cm in diameter. During the training phase post-response feedback was given in the form of a cartoon character's picture (e.g., SpongeBob) which was either smiling (after correct responses) or crying (after incorrect ones). SpongeBob's pictures, measuring 20×13 cm each, were presented in the centre of the monitor screen and displayed for 2 seconds. The participants answered orally to the bisection task and the experimenter pressed the corresponding keyboard key response ("S" for "short", "L" for "long"). The distractor took the form of a 4 cm diameter circle and was randomly selected among 10 different complex rosettes (cf. Figure 1).





*Figure 1.* Illustration of the complex rosettes used as distractor.

As exposed Figure 2, the only constraint related to the spatial location of the distractor was that it had to be 4 cm away from the edge of the temporal stimuli. In other words, distractors could appear totally randomly within the gray area. The moment in which the distractor appeared was also completely randomised, with the only constraint being that it had to be exposed at the same time as the temporal stimulus, outside the 50ms area constituting the beginning and the end of the appearance of the temporal stimulus. On the other hand, the duration of appearance of the distractor was fixed at 40ms.



*Figure 2.* Illustration of the fixed spatial location associated with temporal stimuli (black area) and the random spatial location of the distractors (gray area).

### **Procedure**

**Temporal task.** All participants performed two temporal bisection tasks, one with short-range durations and the other one with long-range durations. The presentation order was counterbalanced across participants. The fulfillment of each of the two range conditions was done on two distinct days. Within the short range durations, the short standard duration was 400ms and the long standard duration was 1500ms. Non-standard durations were 675, 950 and 1225ms. Within the long range durations, the short standard duration was 600ms, and the long standard duration was 2400ms. Non-standard durations were 1050, 1500 and 1950ms.

For each temporal bisection task participants had to go through three successive phases: a pre-training phase, a training phase and a testing phase. In the pre-training phase the individual was submitted twice to the “long” and “short” standard durations. These

presentations were accompanied by experimenter's instructions. For the short standard these were: "Look, this is the short circle. It stays on the screen for a short time.". For the long standard these were: "Look, it's the long circle. It stays on the screen for a long time.".

In the training phase participants were exposed to a block of 8 trials, where standard durations were presented four times each, randomly. Each trial began with the word "ready", following an inter-trial interval randomly selected between 500 and 1000ms. When the participant said he/she was ready, the experimenter pressed the spacebar to trigger the stimulus presentation after a fixed time of 250ms. In this phase participants had to answer by themselves, namely they were required to press the keyboard "S" key in case they saw the short circle, or the keyboard "L" key if they saw the long circle. In the case of a correct answer the picture of a smiling SpongeBob was displayed for 2s, and that of a crying SpongeBob in the case of an incorrect one. Following these eight trials, and if the success rate was greater than 75%, the participant was invited to pursue with the testing phase. However, if the success rate was lower than this threshold, he/she had to start again from the pre-training phase. The experiment was stopped if, after three attempts, the individual was failing the training phase (although this never happened in our study).

In the testing phase non-standard durations were inserted along with standard ones. Participants were not informed of this change and their tasks remained unchanged. Nonetheless, distractors were also integrated while feedbacks were no longer displayed. These later novelties were indicated by the experimenter with the following instruction "Great ! Let's continue playing, but watch out ! Now circles can come on the screen to distract you ! Moreover, SpongeBob will no longer be there to tell you if you have succeeded or not". The participant then had to perform 8 trials for each of the 5 durations with and without distractors (80 trials), all presented in a random order.

**Neuropsychological tests.** On the second day, following the last temporal bisection task, each participant had to complete a total of three randomly addressed neuropsychological tests. One of those was the "Sky Search" subtest of the Test of Everyday Attention for Children, which aims at assessing selective attention (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). In this test a large sheet containing 130 pairs of five different spacecrafts was presented to the participant. The individual's objective was to pair all of the identical spacecrafts as quickly as possible (score = required time / spacecraft found). Another test was the Corsi-block tapping test (Corsi, 1972), in which the participant immediately repeated the sequence of tapping blocks previously presented by the experimenter in the same order (short-term memory score) and then in the reverse order (working memory score). This test contained 8 tapping

sequences ranging from 2 to 9 blocks, with two trials per block sequence. The test stopped when the participant failed both trials of the same sequence. Therefore, the score was the number of sequences reproduced without error by the participant. Finally, in order to assess inhibition, individuals had to complete the Nepsy subtest (Korkman, Kirk & Kemp, 1997), which is commonly known as "Knock and Tap". During the first sequence of this test the person had to immediately perform the opposite of the experimenter's gesture (e.g., tapping if the experimenter knocked, and vice versa). For the second phase the rules were changed: when the experimenter knocked, participants had to immediately put their fists in the palm of the hand, when the experimenter knocked, they were not supposed to do anything and when the experimenter put the fist in the palm of his hand, participants had to knock. Each phase consisted of 15 elements and the test stopped when the individual made four mistakes in a row. The experimenter scrupulously followed the Nepsy test card, exposing the gestures he had to perform. The score on this subtest was the number of correct motor actions. These specific tests have been used to be linked with previous studies (Hallez & Droit-Volet, 2017, 2019).

## **Results**

### **Temporal performances from non-distractor to distractor trials**

Figure 3 shows the mean proportion of long responses during the test phase associated with each group age plotted against stimulus duration, for non-distractor and distractor trials, for each of the range duration (short vs. long).

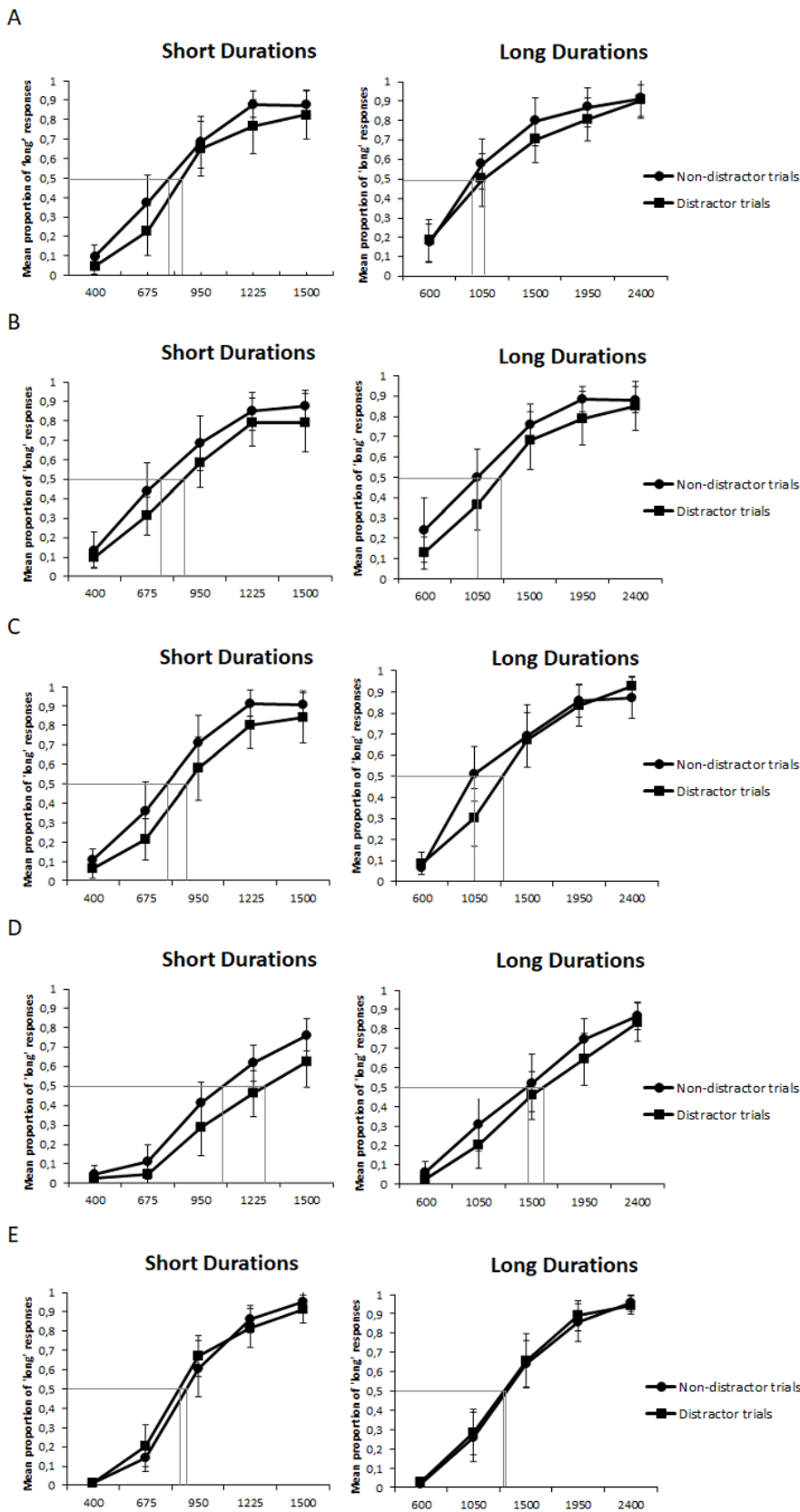


Figure 3. Proportion of long responses plotted against the stimulus durations for each the distractor and non-distractor trials within short and long range for (A) 5 year-olds, (B) 6 year-olds, (C) 7 year-olds, (D) 8 year-olds and (E) adults.

In order to analyse the psychological functions, Bisection Points (BP) and Weber Ratios (WR) were calculated for each subject in each distractor's condition. The BP refers to the temporal stimulus giving rise to 50% "long" (or "short") responses. Although there are various ways of calculating it, the different methods led to very similar results (Wearden & Ferrara, 1995). In the present investigation we used the Pseudo-Logistic Model (PLM: Killeen, Fetterman, & Bizo in 1997) as this has been widely deployed and usually provides very good fits to bisection data (Allan, 2002; Brown, Höhn, Faure, Von Hörsten, Le Blanc, Desvignes, El Massioui & Doyère, 2011; Grommet, Droit-Volet, Gil, Hemmes, Baker & Brown, 2011). On the other hand, the WR is a measure of variance and represents the difference limen divided by the bisection point. All regressions calculated on our data produced an average  $R^2$  values of 0.90. When the program failed to converge the results, the bisection point was calculated by linear interpolation. Nonetheless, 4 observations (e.g., two 5 year-olds, one 6 year-old and one 7 year-old), still could not be converged because of erratic answers, and this represents 1.05% of the data section. We did not include these observations in the analysis, but did not exclude the participant. It is also important to point out that the independent variables have all been centered before treatment.

An analysis of variance (ANOVA) was first performed on the bisection points with two within-subject factors (Range Duration, Distractor Condition) and a between-subject factor (age group). The ANOVA unveils a main effect of both range duration  $F(1,112) = 74.30, p < .001, \eta^2_p = .40, (1 - \beta) = 1$ , and distractor condition  $F(1,112) = 60.76, p < .001, \eta^2_p = .18, (1 - \beta) = .98$ . This indicates that the participants understood the task since the bisection point value associated with short-range ( $M = 963.99$ ) is lower than the long-range one ( $M = 1229.90$ ). Independently of the duration, it also suggest that the appearance of a distractor shortens the time perception of subjects as bisection points are further shifted to the right for distractor trials ( $M = 1202.40$ ) than non-distractor trials ( $M = 942.94$ ). The ANOVA also shows a main effect of age  $F(1,112) = 20.13, p < .001, \eta^2_p = .42, (1 - \beta) = 1$ . Furthermore, the age interacted with each of our within-subject factors. The significant age in months  $\times$  range duration  $F(1,112) = 2.92, p = .02, \eta^2_p = .09, (1 - \beta) = 0.77$  meant an increasing difference in bisection point's values from long to short range durations with age (5 year-olds:  $M = 123.66, SE = 409.54$ ; 6 year-olds:  $M = 220.65, SE = 376.25$ ; 7 year-olds:  $M = 265.64, SE = 227.01$ ; 8 year-olds:  $M = 257.24, SE = 357.51$ ; adults:  $M = 447.37, SE = 236.87$ ), although additional independent t-tests only reveal differences between adults and each of the child groups (for all Bonferroni tests  $ps < .05$ ),

whereas no statistical differences between children emerged (for all Bonferroni test  $ps > .1$ ). Regarding the significant age in months  $\times$  distractor condition  $F(1,115) = 20.10, p < .001, \eta^2_p = .15, (1 - \beta) = 0.99$ , the same pattern of results was observed since means increase with age (5 year-olds:  $M = -235.93, SE = 299.96$ ; 6 year-olds:  $M = -296.28, SE = 277.69$ ; 7 year-olds:  $M = -344.54, SE = 217.93$ ; 8 year-olds:  $M = -215.29, SE = 358.51$ ; adults:  $M = 34.27, SE = 139.83$ ), but differences only appeared significant when child groups were compared with adults performances (in all Bonferroni test  $ps < .05$ ). The averages being further negative for children than they are for adults, this indicates that the bisection points associated with distractor trials are further shifted to the right for the youngest. This therefore implies that children further underestimate the time from non-distractor to distractor trials compared to adults (5 year-olds compared to adults:  $t(45) = -4.00, p = .001$ ; 6 year-olds compared to adults:  $t(50) = -4.10, p < .0001$ ; 7 year-olds compared to adults:  $t(49) = -7.27, p < .0001$ ; 8 year-olds compared to adults  $t(51) = -3.25, p = .001$ ). This testifies the slow maturation of the process allowing to fight against the interferences of the distractor. Additional paired t-tests comparing the differences in bisection point values between non-distractor and distractor trials to a value of zero confirmed that adults did not generate statistical differences between condition of distractors ( $t = 1.23, p = .23$ ), while all children age brackets showed significant distracting effects (5years:  $t = -3.52, p = .002$ ; 6years:  $t = -3.92, p = .001$ ; 7years:  $t = -7.74, p < .001$ ; 8years  $t = -3.06, p = .005$ ). Other interactions failed to reach significance (range duration  $\times$  distractor condition:  $F(1,115) = 0.06, p = .81$ , range duration  $\times$  distractor condition  $\times$  age in months =  $F(1,115) = 0.01, p = .94$ ).

The same ANOVA was launched on the measure of the Weber Ratios. Only the effect of age was proved to be significant  $F(1,112) = 2.71, p < .03, \eta^2_p = .08, (1 - \beta) = 0.73$ , indicating that age in months explains 8% of Weber ratio variances. Once again, averages decrease slowly and gradually ( $M_{5years} = .36; M_{6years} = .34; M_{7years} = .29; M_{8years} = .29; M_{adults} = .17$ ) but independent t-test are proved significant only when children groups are compared with adults (all Bonferroni test  $ps < .05$ ). No other effects emanates from the ANOVA (distractor condition:  $F(1,115) = 2.13, p = .15$ ; range duration:  $F(1,115) = 0.77, p = .38$ ; age  $\times$  distractor condition:  $F(1,115) = 0.85, p = .36$ ; age  $\times$  range duration:  $F(1,115) = 0.22, p = .64$ ; distractor  $\times$  range duration:  $F(1,115) = 2.31, p = .13$ ; distractor  $\times$  range duration  $\times$  age:  $F(1,115) = 0.01, p = .92$ ).

### Mediation Analysis

To test the hypothesis that inhibition scores mediated the relationship between age and the contraction between the non-distractor to distractor trials, analyses of mediation were conducted following the guidelines provided by Preacher and Hayes (2008). Age was coded -1 for the 5 year-olds, -0.5 for the 6 year-olds, 0 for the 7 year-olds, 0.5 for the 8 year-olds and +1 for the adults. The inhibition scores were mean-centred across all participants. The results of this mediation analysis are displayed in Figure 4. First, age predicted the temporal contraction,  $B = 0.44$ ,  $t(118) = 3.43$ ,  $p < .001$ ,  $\eta^2_p = .09$ ; 95% CIs (0.19, 0.70). As previously exposed, this indicates a decreasing contraction with age. Second, age was significantly associated with inhibition scores,  $B = 0.56$ ,  $t(118) = 4.54$ ,  $p < .001$ ,  $\eta^2_p = .39$ , 95% CIs (0.32, 0.81); the increasing age leading to an increase in inhibition capacity (5 year-olds:  $M = 23.94$ ,  $SE = 8.12$ ; 6 year-olds:  $M = 25.24$ ,  $SE = 5.57$ ; 7 year-olds:  $M = 28.29$ ,  $SE = 3.00$ ; 8 year-olds:  $M = 27.73$ ;  $SE = 3.18$ ; adults:  $M = 29.72$ ,  $SE = 0.54$ ). In addition, inhibition scores were positively associated with temporal contraction,  $B = 0.34$ ,  $t(118) = 3.69$ ,  $p = .0003$ ,  $\eta^2_p = .40$ , 95% CIs (50.06, 165.68). Thus, the mediation analysis was tested using a bootstrapping method with bias-corrected confidence estimates (Preacher & Hayes, 2004). The 95% confidence interval of the indirect effects was obtained with 5,000 bootstrap resamples. Results of this mediation analysis confirmed the indirect effect of inhibition in the relationship between age and time contraction caused by a distractor  $B = 0.19$ ; 95% CIs (.08, 0.35). In addition, the direct effect of age on the temporal contraction became marginal when controlling for inhibition scores,  $B = 0.25$ ,  $t(118) = 1.89$ ,  $p = .06$ .

In order to show the predictive superiority of inhibition in our experimental context, we tested this mediation model using, one by one, each of the cognitive components measured in our experiment (i.e., short-term memory, working memory, and selective attention). The scores obtained by the participants on the different neuropsychological tests are visible Table 1. Nevertheless and as expected, the three mediations models failed to be significant as none of these cognitive variables showed a direct effect on the temporal contraction (short-term memory :  $B = 0.05$ ,  $t(118) = 0.60$ ,  $p > .55$ ; working-memory :  $B = 0.14$ ,  $t(118) = 1.46$ ,  $p = .15$ ; selective attention :  $B = 0.10$ ,  $t(118) = -1.01$ ,  $p = .31$ ).



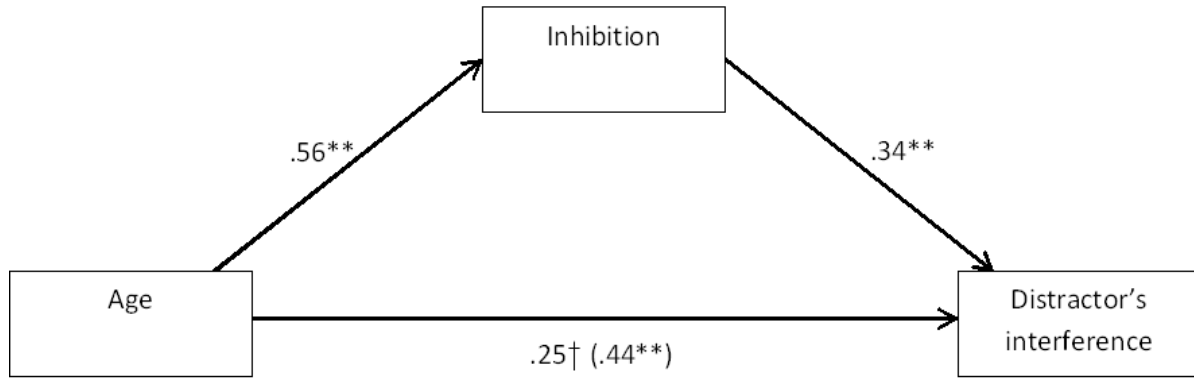


Figure 4. Indirect effect of age on time contraction from non-distractor to distractor trials.

Notes. Values indicate non-standardized regression coefficients (B) with and without (in brackets) the control of inhibition. † $p < .10$  ; \* $p < .05$ ; \*\* $p < .001$ .

Table 1. Mean, Standard Deviation, minimum and maximum of the raw scores of different neuropsychological tests.

	5 years			6 years			7 years			8 years			Adults		
	M	SD	[Min, Max]	M	SD	[Min, Max]	M	SD	[Min, Max]	M	SD	[Min, Max]	M	SD	[Min, Max]
Short-term memory															
(Corsi Block Tapping Test - forward)	3.47	1.39	[1; 6]	4.21	1.86	[1; 8]	4.79	1.82	[2; 8]	4.65	0.94	[2; 6]	5.40	0.96	[4; 7]
Working memory															
(Corsi Block Tapping Test - reverse order)	3.00	1.80	[1; 8]	3.78	2.23	[2; 8]	4.57	1.83	[2; 8]	3.92	0.79	[2; 5]	4.84	0.75	[4; 6]
Inhibition (Knock and Tap)	23.94	8.12	[5; 30]	25.24	5.57	[15; 30]	28.29	3.00	[17; 30]	27.73	3.18	[16; 30]	29.72	0.54	[28; 30]
Selective attention (Sky Search)	11.47	6.74	[5; 25]	9.97	3.34	[6; 18]	8.70	3.08	[4; 18]	6.69	1.47	[4; 11]	2.97	0.59	[2; 5]

## Discussion

This experiment investigated the effect of attentional distraction within a temporal visual bisection task in children aged 5 to 8 years old, and in adults. The obtained psychophysical functions revealed that, in different age groups, the proportion of long responses increased as a function of stimulus duration, although the functions were flatter in children. The presented data are thus in accordance with previous developmental literature using temporal bisection task and showing that time sensitivity increases with age (de Lurdes Delgado & Droit-Volet, 2007; Droit-Volet, 2017; Droit-Volet & Rattat, 2007; Hallez & Droit-Volet, submitted; Rattat & Droit-Volet, 2005). Of our greater interest, this study also shows that the non-temporal distractor shortens children's time judgments, resulting in bisection points further shifted to the right in the distractor condition compared to the non-distractor condition.

However and contrary to Gautier and Droit-Volet (2002), we proved that this contraction of time was greater in the youngest participants and decreased with the increasing age, thereby validating our first hypothesis. In addition, our investigation's originality lies in the fact that this age-related decrease in the shortening effect was specifically related to the improvement of inhibition skills. Indeed, as shown by the mediation model, the direct age effect on the contraction is significant, but becomes marginal when the inhibition is entered as a mediator. Thereby, when attention is diverted away from the passage of time because of the lack of inhibition, it creates further interferences. This finding is also in line with brain imaging studies showing that the pre-frontal cortex is activated in explicit time judgments (Coull, Cheng & Meck, 2011).

The question that remains to be elucidated is the nature of the mechanism engendering this underestimation of time. Previous literature has shown that time processing involves memory or attention, leading to poorer performances on longer durations (Brown & West, 1990; Hallez & Droit-Volet, 2017; Lieving, Lane, Cherek & Tcheremissine, 2006). However, in our study the margin of error remained constant across the two range-durations (short vs long). The lack of interaction between the effect of distractor condition and duration-range for both the bisection point and the Weber Ratio suggests that the underlying mechanism of the distractor is general and independent of the matched duration. Yet, in our study, the durations used were rather short (e.g., less than or equal to 2.5 seconds), which rather imply inhibition capacities (Droit-Volet, 2010). Other studies are therefore necessary to generalize the effect on

longer durations. Also, the effect of age on the temporal contraction mediated by the effect of inhibition seems to draw a specific interference. In accordance with the previously proposed internal clock models (Church, 1984; Gibbon, Church & Meck, 1984, Zakay & Block, 1996, 1998), this could draw the effect of an attentional-switch system. Thereby, if an individual does not have enough inhibition skills, he/she will then have more chances to accidentally treat the irrelevant non-temporal information. Consequently, the switch will surreptitiously open and a certain amount of time units (e.g., pulses) will be lost, which will lead to a decrease in subjective time.

Our study thus refines the central executive functions accounted for age-related differences in temporal performance in a concurrent task condition. Based on a recent article of Hallez and Droit-Volet (2017), the authors concluded that it is the attentional gate, governed by selective attention, that predicts the underestimation of time within a dual-task. Nonetheless, in our study it is the cognitive component of inhibition that predicts the underestimation caused by a distractor. This therefore suggests the existence of two attentional mechanisms. Following the operating logic of the two attentional mechanisms proposed by Zakay and Block (1996, 1998, and presented in the introduction) an attentional-switch, mastered by inhibition, would close to process temporal stimuli and open at the end of a stimulus to be timed or when the main treatment becomes non-temporal. All else being equal, the interference within the same subject should not cause significant differences across durations (short vs long) as it results from a similar process. In sum, our outputs would result from the effect of an attentional switch-like mechanism directly related to the control of attention.

Nonetheless, once the switch is closed, another interference of a different nature may still occur, this one acting on the attentional gate. However, the underestimation of time caused by this second interference would be related to selective attention and dependent on the duration (Hallez & Droit-Volet, 2017). In our study, we did not observe this kind of interference as attentional resources required to treat the distractor were very restricted by its extremely short appearance (e.g., 40ms). Indeed, previously conducted studies showing a resource-based interference have employed specific tasks which are very greedy in attentional resources, such as a dual-task, where non-temporal information has to be processed simultaneously with temporal information (Casini & Macar, 1997; Coull, Vidal, Nazarian & Macar, 2004; Fortin & Couture, 2002; Gaudreault, Fortin, & Macar, 2010; Hallez & Droit-Volet, 2017, 2019; Kladopoulous, Hemmes & Brown, 2004). This would therefore attest the precedence of the attentional-switch on the attentional-gate.

Nonetheless, in our study, age as such remains a variable of interest responsible of attentional-control interferences as it is still marginal when inhibition is controlled. One could thus question how this supports the attentional switch-like system. It has already been proposed that the closure delay when starting to time an event corresponds to participants' reaction time, at least for a duration that is shorter than 2.5s (Droit-Volet, 2010). There is now ample evidence showing that the time taken to generate a motor action, assessed by means of a simple reaction time is longer and more variable in younger children (e.g., Kail & Ferrer, 2007; Riggs, McTaggart, Simpson, & Freeman, 2006). If we assume that the switch's oscillation depends on the reaction-time, then the reaction time not only predicts the closing of the switch at the beginning of the time processing, but also the closing whenever the switch opens. In other words, individuals with a higher reaction time could potentially close their attentional-switch quicker than low reaction time individuals, thereby returning more quickly to a state where they can integrate temporal impulses. This would thus extend the results of Droit-Volet (2010), as the interference made by the motor component would not be specific to the temporal reproduction task, on the contrary, it would be specific to the measurement of time in children since the reaction time could be accounted for controlling the delay of the switch's opening or closing. This extremely interesting hypothesis would deserve to be tested in a systematic way before being validated.

However, for the sake of parsimony, it is important to specify that these results may be associated with the characteristics of the distractor used. For instance, time perception studies which focused on the dual-task paradigm have highlighted the fact that time interference effects depend on the concurrent task used (Hallez & Droit-Volet, 2019). Also cognitive studies on the influence of distractors have shown that the ability not to process the distracting information is not unitary and reveals itself in different guises, likely reflecting multiple underlying neural architectures and processes (Chelazzi, Marini, Pascucci & Turatto, 2019; Geng, 2014). Faced with the shortage of articles analyzing the developmental influence of distractors on attention and time perception, more studies are needed in order to be able generalize the effects obtained, beyond the very characteristics of the distractor (e.g., size, appearance duration and delay of appearance of the distractor used). The difficulty also remains in the fact that selective attention and inhibition are constructs that very often overlap. Indeed, several studies have shown that distractor learning can have effects on attentional selection (Rankin, Abrams, Barry & al., 2009) which can help to filter out the distractor (Noonan, Crittenden, Jensen & Stokes, 2018; Gaspelin & Luck, 2018; van Moorselaar & Slagter, 2020).

In summary, our study examined the direct connection between individual capacities (i.e., selective attention, inhibition, working memory, and short-term memory) and estimation in temporal visual bisection, with or without a distractor. The results showed a time contraction caused by the distractor, which gradually decreased with age. This age-related effect was mediated with inhibition scores, while none of the other cognitive dimensions were of great interest. Based on recent developmental studies, we proposed a categorisation of the attentional interferences in time processing: one related to our results, based on attentional control and mastered by inhibition, and the other one related to the literature, based on attentional resources. The first type of interference can be linked to the attentional switch, and the latter to the attentional gate.

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