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The Dynamics of Interference Control across Childhood and Adolescence: Distribution Analyses in Three Conflict Tasks and Ten Age Groups

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Interference control is central to cognitive control and, more generally, to many aspects of development. Despite its importance, the understanding of the processes underlying mean interference effects across development is still limited. When measured through conflict tasks, mean interference effects reflect both the strength of the initial automatic incorrect response activation by the irrelevant stimulus dimension and the capacity to subsequently suppress this tendency and/or activate the correct response. To investigate the development of interference control, we focused on the time course of these activation and/or suppression processes studied in 360 children distributed in 10 age groups (from 5 to 14 years of age) and 36 adults. Each participant performed the three mostly used conflict tasks (Simon, flanker, and Stroop) designed to be sensitive across the whole age range. Performances were analyzed using distribution analyses of accuracy and response times. Conditional accuracy functions highlighted conflict-dependent developmental changes in the time course of the initial incorrect response capture and later controlled correct response activation: these results revealed a mature pattern for Simon from 5 years onwards (the easiest task as assessed by fastest RT and highest accuracy), late maturation in Stroop (the most difficult task), intermediate in flanker. In contrast, despite the increased speed of responses across the age range, the shape of correct response distributions did not change with age, leaving open the maturation of suppression processes. Results are discussed with respect to the interest of the methodology used and debates on the interpretation of the dynamics at hand.

Keywords: Interference control; inhibition; conflict tasks; distributional analyses
Supplemental materials: http://dx.doi.org/10.1037/dev0001122.supp

Children and teenagers are more than ever surrounded by huge amounts of information that can easily distract them from their current goals (listening to the teacher instead of reading the last posts on a social network; keeping in mind the question they have to address in their presentation while searching on the internet instead of browsing attractive websites. . .). Interference control that allows for acting in a goal-directed manner without getting distracted by potential sources of interference is a core component of cognitive control. The efficiency of interference control during early childhood has been shown to account, at least in part, for individual differences in many domains of cognitive development, such as language ability (e.g., Choi & Trueswell, 2010; Gandolfi & Viterbori, 2020) or theory of mind (e.g., Carlson, Claxton, & Moses, 2015; Tsuji & Mitchell, 2019) but also in school performance in mathematics and reading (e.g., Bull & Lee, 2014; Colé, Duncan, & Blaye, 2014). More generally, it is associated with a better quality of life in adulthood (Moffitt et al., 2011; see Diamond, 2013 for a review). Despite its key role in many aspects of a successful life, only a handful of studies have gone beyond observing an overall increased ability to control interference across childhood and adolescence, and have tried to disentangle the underlying processes (Ambrosi, Servant, Blaye, & Burle, 2019; Cragg, 2016; Erb & Marcovitch, 2018; Erb, Moher, Song, & Sobel, 2018). However, since these studies differ in terms of age ranges examined and tasks used, it is not easy to bridge the gap to obtain a global picture of potentially conflict-dependent

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developmental trajectories over the entire period of interest. The present study aimed to provide a detailed account of interference control development across childhood and adolescence and over a range of conflict tasks. To that end, it carefully examined the dynamics of the processes underlying mean interference effects. More specifically, based on dual-routes models (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Ridderinkhof & van der Molen, 1995), the present study scrutinized the interplay, during interference resolution, between the activation of the automatic response induced by prepotent interfering information, its suppression, and/or the activation of the slower controlled goal-based response. This was achieved using distributional analyses of both accuracy and response times (RTs), which have proven to be very useful in adults in advancing our understanding of the dynamics of interference control. Such analyses have been seldomly used in children and never across the entire childhood span. We applied these analyses to the performance of 360 children aged from 5 to 14 as well as a group of young adults who were all presented with three different conflict tasks.

Interference Control in Conflict Tasks

Interference control is usually assessed through conflict tasks such as the Simon (Simon, 1990), the Stroop (Stroop, 1935), and the flanker (Eriksen & Eriksen, 1974). All three tasks require participants to respond to one dimension of a stimulus and ignore another irrelevant, but prepotent one, which shares characteristics with the response and/or the relevant stimulus dimension. In the typical Simon task, participants must use a right- or left-hand response as a function of a relevant feature of the stimulus (for example its color). Although irrelevant for the task at hand, the stimuli are presented lateralized, either on the same side as the required response (compatible trials) or on the opposite side (incompatible trials). In the standard Stroop task, participants must name the color of the ink of a written color word, which can be compatible with its color (i.e. "blue" written in blue) or incompatible ("red" written in blue). In the flanker task, participants must respond as a function of the nature of a central target stimulus (e.g. "H" or "S") which can be flanked either by a repetition of the same letter ("HHH") or a repetition of the alternative target (e.g. "SHS"). When the two dimensions of the stimulus lead to different responses (incompatible trials), participants must refrain from responding to the irrelevant, prepotent dimension, and select the response associated with the relevant one. Lower performance (on both accuracy and reaction times) on incompatible trials than on compatible trials, also known as interference effect, is classically reported. According to dual-route models, interference effects stem from the fact that the irrelevant dimension of the stimulus rapidly and automatically activates the corresponding response via a direct route (for example a stimulus presented on the left automatically activates left responses in a Simon task) while the relevant dimension of the stimulus requires to be translated into the correct response as a function of task instruction via a slower, deliberate and more controlled route (e.g., De Jong et al., 1994). Consequently, it is assumed that the mean interference effect reflects both the strength of the initial automatic response activation (the stronger the activation, the larger the interference), and the capacity to subsequently suppress this tendency and/or activate the correct response. In such interpretation, timing is the key. To better assess the temporal aspects of interference control in conflict tasks, distribution analyses have proved to be particularly informative. They are based on the vincentization technique which bins distributions of performance into classes of equal size based on response latencies (for detailed descriptions, see Ambrosi et al., 2019). Distributional analyses of accuracy, also known as conditional accuracy functions (CAFs, Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Lappin & Disch, 1972), plot accuracy as a function of responses latencies. Studies in adults have evidenced a drop in accuracy in the three conflict tasks on fast incompatible trials followed by an increased performance on slower ones and almost perfect accuracy on the slowest incompatible trials. In contrast, CAF on compatible trials remains much flatter and close to ceiling performance across latencies (e.g., Gratton et al., 1988; van den Wildenberg et al., 2010 for overviews). Importantly, the pattern on incompatible trials is in line with the predictions of dual-route models: The initial drop in accuracy suggests the initial fast and transient response capture by the irrelevant dimension of the stimulus, whereas increased accuracy with longer latencies is consistent with a later activation of the correct, instruction-based, response, along with active suppression (Ridderinkhof, 2002) and/or spontaneous decay (Hommel, 1994; Simpson & Riggs, 2007) of the incorrect one. Additionally, plotting the cumulative density functions (CDF) of RTs allows for a comparison of the distributions of RTs on compatible and incompatible trials. From these distributions, one can extract the so-called "delta plots", corresponding to the size of the chronometric interference effects (incompatible - compatible RTs) as a function of the response latencies (Ridderinkhof, 2002; van den Wildenberg et al., 2010). In adults, delta plots revealed increased interference effects for slower responses in the flanker (i.e., positive-going delta plots; Burle, Spieser, Servant, & Hasbroucq, 2014; Ridderinkhof, Scheres, OosterIaan, & Sergeant, 2005) and Stroop (Pratte, Rouder, Morey, & Feng, 2010) tasks but reduced, or even null, interference effects for longer latencies in the Simon task (i.e., negative-going delta-plots; Burle, Possamaï, Vidal, Bonnet, & Hasbroucq, 2002; Ridderinkhof, 2002; Wylie et al., 2010). These contrasting patterns, depending on the task at hand, suggest critical task differences in the origin and the dynamics of the interference (see Pratte et al., 2010 for empirical

comparisons and Speckman, Rouder, Morey, & Pratte, 2008 for theoretical considerations). From a functional point of view, the dynamics of the chronometric interference effect across response latencies has been originally considered to index the suppression of the initial response activation (Ridderinkhof, 2002) which would be weaker and/or occur later for the Stroop and flanker tasks than for the Simon task. Whereas Ridderinkhof's interpretation suggests active suppression, Ulrich, Schröter, Leuthold, and Birngruber (2015) have recently proposed a model that remains explicitly agnostic as to the origin of the automatic response decrease, claiming that it remains consistent with both spontaneous decay and active suppression. Ulrich and colleagues extended diffusion models (e.g., Ratcliff & McKoon, 2008) to conflict tasks by introducing an automatic activation component that spills over the deliberate decision process, accelerating or decelerating it depending on the compatibility of the relevant and interfering dimensions. This model, so far the only one adequately fitting the data in different conflict tasks, both in adults (Servant, White, Montagnini, & Burle, 2016; Ulrich et al., 2015) and in young children (Ambrosi et al., 2019), revealed that the slopes of delta plots are basically determined by the time course of the automatic response activation. More specifically, the simulation have evidenced that if the peak of the automatic activation is reached early, the delta function tends to be negative (as in Simon) whereas if it occurs late, the delta function tends to be positive (as in Stroop and flanker). Differences in the dynamics of chronometric interferences may also stem from the nature of the conflict in each task. While in the flanker and Stroop tasks, conflicts in incompatible trials result from the overlap between two dimensions of the stimulus (target letter vs. flanker letters in the flanker task, the color of ink vs. written color name in the Stroop task), conflicts in the Simon task emerge from an incompatibility between an irrelevant dimension of the stimulus (its location) and the location of the response hand (Egner, 2007; Kornblum et al., 1990; Kornblum, Stevens, Whipple, & Requin, 1999; Kornblum & Lee, 1995).

The Development of Interference Control: From Mean Interference to the Dynamics of the Underlying Processes

Most studies that include participants from a wide age range have primarily focused on mean interference effects that offer no hint on the development of the processes underpinning the conflict effect (e.g., Davidson, Amso, Anderson, & Diamond, 2006; Ikeda, Okuzumi, & Kokubun, 2014; Pozuelos, Paz-Alonso, Castillo, Fuentes, & Rueda, 2014; Wright, Waterman, Prescott, & Murdoch-Eaton, 2003). Although they revealed an overall reduction of the mean interference effect across childhood, taken as an index of the improvement of control efficiency, there are important differences in the developmental conclusions to be drawn depending on tasks. Progress in interference control has been evidenced in children between 6 and 11 years of age in the Simon task by Davidson et al. (2006; but see Sheridan, Kharitonova, Martin, Chatterjee, & Gabrieli, 2014 for a lack of reduction of the interference effect in this age range). Turning to the Stroop task, improvement of interference control was observed in children between 3 and 6 years of age (Prevor & Diamond, 2005) and from 6 years up to adulthood depending on the numerous versions of the task (e.g. Archibald & Kerns, 1999; Jongen & Jonkman, 2008; Macdonald, Beauchamp, Crigan, & Anderson, 2014). In the flanker task, adult-like interference effect is evidenced by the age of 7 for some versions of the task (Checa, Castellanos, Abundis-Gutiérrez, & Rueda, 2014; Davies, Segalowitz, & Gavin, 2004; Rueda et al., 2004) and not before adolescence or even young adulthood for other versions (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Waszak, Li, & Hommel, 2010). These differences depending on the conflict-tasks used or even on the version of conflict task per se (Macdonald et al., 2014) are plausibly linked to between- studies methodological variations, like the complexity of rules to keep in mind, the modality of response, the response set itself. Differences in the processes to be controlled inevitably impact the efficiency of control. In order to go beyond the developmental changes of mean interference effects and get a better understanding of the processes at stake, two approaches have been adopted: (a) The analysis of responses trajectories in "reach tracking versions" of conflict tasks (participants are asked to produce a reach movement towards the selected response target) that allows the initiation times and reach curvatures of the movement to be investigated. Such an analysis dissociates two control processes: response threshold adjustment involving the inhibition of motor output, and controlled selection between conflicting response alternatives. This approach has been used in studies both with adults (e.g., Erb, Moher, Song, & Sobel, 2016) and, more recently, with children (Erb & Marcovitch, 2018; Erb et al., 2018). A second approach (b), adopted in the present paper, which does not require any change of settings from standard "button-press" conflict tasks, consists in analyzing in more detail the whole distribution of RTs (correct and errors). In typical conflict tasks, research in adults have shown that these analyses highlight the within-trial dynamics of interference control, by dissociating initial automatic response activation from later controlled response selection. A few studies have used distributional analyses in children but they usually did so on narrow age ranges thereby pointing for the need for further research to provide a full picture of developmental trajectories of the temporal dynamics of interference control across childhood and adolescence (Ambrosi et al., 2019; Bub, Masson, & Lalonde, 2006; Iani, Stella, & Rubichi, 2014; Ridderinkhof et al., 2005; Stins, Polderman, Boomsma, & de Geus, 2007). Based on CAFs

analyses, Stins et al. (2007) observed an initial drop in accuracy for the shortest responses in an arrow-flanker and Simon tasks in 12-years old children and Bub et al., (2006) obtained the same pattern of results in 7- to 11-years old performing a Stroop task. Using an arrow-flanker task in a group of twenty-two boys aged from 6-12 years, Ridderinkhof et al., (2005) showed that children's pattern of accuracy was similar to the one observed in adults. Turning to RT distributions, the delta plot analyses conducted by Bub et al. (2006) in a Stroop task revealed developmental differences: The interference effect increased with RTs for older children (9- to 11-year-olds), as typically observed in adults, while it diminished with longer response latencies in younger children (7- to 9 years old). In the Simon task, Iani, et al. (2014) showed that the interference effect was present for fast responses and decreased as RTs increased in 1st and 2nd graders (6 and 7 years old), as for adults. This decrease appeared weaker in 1st graders who showed the interference effect across all the RTs bins (i.e., across the whole distribution of RTs). In contrast, in 2nd graders, this effect was absent for the last bin (i.e., for slowest RTs). Altogether, developmental literature suggests the interest of such an approach revealing both commonalities and differences between children and adults' dynamics. In a recent study, Ambrosi et al. (2019) went a step further in using a within-participants design that presented children's-adapted versions of a Stroop, flanker and Simon tasks to 5 to 6-year-old children. They performed distribution analyses and obtained evidence for the initial incorrect response capture as demonstrated by the drop in accuracy for the shortest latencies in all three tasks. However, whereas the probabilities of the correct response, in both compatible and incompatible trials, tended to converge towards perfect response accuracy for flanker and Simon tasks with longer response latencies, it remained below ceiling for incompatible trials in the Stroop task. Considering CDFs, the authors obtained a pattern similar to the one typically observed in adults with a difference between compatible and incompatible trials distributions which increases as RTs lengthen for flanker and Stroop task, and decreases for the Simon task. This study, however, does not address developmental trajectories of the dynamics of control processes, and a final conclusion on the influence of conflict tasks is hampered by the use of a different set of stimuli in each task. Altogether previous studies remain inconclusive on two main questions (a) the developmental trajectories of the dynamics of response activation and suppression across a wide age range and (b) the extent to which these trajectories may depend on the nature of conflicts. Assessing the dynamics of incorrect and correct response activation and suppression, from 5 to 14 years of age and beyond, to young adulthood, was the goal of the present study. The use of three conflict tasks with the same set of stimuli in a within-participants design should highlight the degree of conflict specificity. Potential task-differences should document the role of the nature of conflict on the development of interference control. More specifically, based on the literature in children (Ambrosi et al. 2019 ; Bub et al., 2006; Iani et al., 2014; Stins et al., 2007), and in adults (Burle et al., 2014; Pratte et al., 2010) we expected to observe differential developmental trajectories of the dynamics of response activation/suppression depending on the conflict task. More specifically, whereas the shape of CAFs may change with increasing age in the Stroop task, it may not significantly evolve in the flanker and Simon tasks. Further, the differences in the evolution of delta plots patterns observed in adults between flanker and Stroop tasks on the one hand and Simon task, on the other hand, may be present from an early age. However, Bub et al. (2006) and Iani et al.'s (2014) data alternatively suggest that some developmental differences may be evidenced, leaving this question open.

Method

Participants

Three-hundred-sixty children from 5 to 14 years old took part in the study (See table 1 for sample distribution). An additional group of young adults was recruited and paid 10 €for their participation. All participants were native French speakers and had a normal or corrected-to-normal vision. They were recruited from kindergartens, primary and secondary schools, and the university of the same middle-class neighborhoods of Aix-Marseille University. Written informed consent was obtained from schools' administrations and each child's/adolescent's legal guardian. Children/adolescents gave verbal assent. All adult participants gave written informed consent. Ethical approval for the study was granted by the "Comité de Protection des Personnes Sud Méditerranée 1" - the regional branch of the independent national ethical committee - under the project name DopControl, Development of Cognitive Control Optimization (ANR-15-CE28-0008-01).

Material and procedure

Children and adults were tested in a within-participants design using child-adapted versions of the three conflict tasks in one session. This involved solving two important challenges: (a) devising versions of the three tasks that would remain sensitive to interference effects from late preschool age to adulthood and (b) maximizing inter-task commonalities to facilitate the interpretation of task differences in terms of the role of the nature of conflict. The three tasks were programmed with and administered through OpenSesame, an open-source graphical experimental platform (Mathôt, Schreij, & Theeuwes, 2012) on a Hewlett-Packard Zbook 15 laptop with a diagonal screen size of 15.6", a resolution of 1024×768 pixels and a refresh rate of 60Hz. Participants sat at an average distance of 40 cm from the computer screen.

Table 1
Sample distributions

Age group	N	School and Grade level	Mean Age	Age S.D. in months	Male/female ratio
5-years old	36	Kindergarten	5 y. 9m.	3	1
6-years old	36	Primary School (PS) 1st grade	6y. 10m.	3	1
7-years old	36	PS 2nd grade	7y. 10m.	3	1
8-years old	36	PS 3rd grade	8y. 10m.	3	1
9-years old	36	PS 4th grade	9y. 10m.	3	1
10-years old	36	PS 5st grade	10y. 9m.	3	1
11-years old	36	Secondary School (SS) 6st grade	11y. 9m.	3	1
12-years old	36	SS 7st grade	12y. 8m.	4	1
13-years old	36	SS 8st grade	13y. 9m.	4	1
14-years old	36	SS 9st grade	14y. 8m.	3	1
Adults	36	University Students	20y. 8m.	30	.894

Stimuli consisted of three sets of two colored line drawings of fruits and vegetables or animals (strawberries/nuts; carrots/bananas; pigs/frogs), they were designed so that each set can be divided into two compatible and two incompatible stimuli and be used in the flanker, the Simon, and the Stroop tasks. The three sets of stimuli were counterbalanced across tasks and participants to ensure that a) all participants saw all three stimuli sets (one set of stimuli per task), and b) all sets would be equally frequently displayed in each task and each age group (e.g. strawberries/nuts were presented for one-third of participants in the Simon task, for one-third in the flanker task and for one-third in the Stroop task for each age group). Stimulus-response mappings for each task were counterbalanced across participants. For all three tasks, stimuli (100 × 100 pixels) appeared in a black frame (320 × 110 pixels) presented in the center of the screen (cf. Figure **??**). For all three tasks, instructions were carefully worded to require a choice among two color options, thereby limiting potential sources of variations between tasks, other than the type of conflict. They were instructed to tell "the color of the picture", "its true color" "the color of the middle picture" in the Simon, Stroop and flanker task, respectively. Two keys corresponding to the two relevant colors were used. Participants had to press with the index finger of their left and right hand (respectively "q" and "5" keys on an AZERTY keyboard with a numerical pad). Since stimuli and hence colors changed across tasks, new stickers with the relevant patches of colors were placed prior to each task onset just above the keys as reminders.

In the Simon task (adapted from Simon & Berbaum, 1988) stimuli appeared either on the left or the right side of the frame (i.e., stimuli appeared 60 pixels away from the middle of the frame which corresponds to an eccentricity 5.1° from screen's center to the middle of the stimulus; see Cao et al., 2013; Iani et al., 2014 for similar eccentricities in child-adapted Simon tasks). A lateralized response was required corresponding to the color of stimuli that were presented on the same side as the requested response (compatible trials) or on the opposite side (incompatible trials). In the flanker task (adapted from Eriksen & Eriksen, 1974 and Servant et al., 2014) stimuli consisted of a row of three drawings, separated by a distance of 10 pixels, making flankers presented at an eccentricity of 5.1° from the screen center. A right or left response was required corresponding to the color of the central drawing whatever it was flanked by the same drawings in the same color (compatible trials) or by another drawing in a different color (incompatible trials). In the Color-Object Stroop task (adapted from Archibald & Kerns, 1999, see also Ambrosi et al., 2017), stimuli consisted of a colored line drawing (100 × 100 pixels) presented in the center of the frame. A lateralized response was required corresponding to the canonical ("true") color of the stimulus. The color displayed on the screen and the canonical color matched on compatible trials but differed on incompatible trials. Children and adolescents were tested individually in a quiet room in their school (adults were tested in the lab).

The same procedure was used for each task: it began with a warm-up ensuring that the participants identified the drawings and knew the canonical color of the represented objects, followed by a training phase and a test phase. The training phase included 24 trials. The first 8 trials were followed by auditory accuracy feedback. Before the 9th trial, participants were informed that there would be no further feedback, and the instructions equally emphasizing speed and accuracy were repeated: "Be careful, you must respond as quickly as possible and without making mistakes". The test phase included 6 blocks of 17 trials, with a short break between each block, on a child request; instructions were given at the beginning of each block. Discarding the first trial, each block included eight compatible and eight incompatible trials controlling for the compatibility on the previous trial (25% of each possible sequence), within-blocks trial sequences were generated using the 'Mix' randomization tool (Van Casteren & Davis, 2006). Each trial began with a fixation point displayed in the center of the frame for 850 ms followed by the stimulus that remained on the screen until a response key was pressed. Each response was followed by a 650 ms blank-screen interval. Each task involved 96 experimental trials and

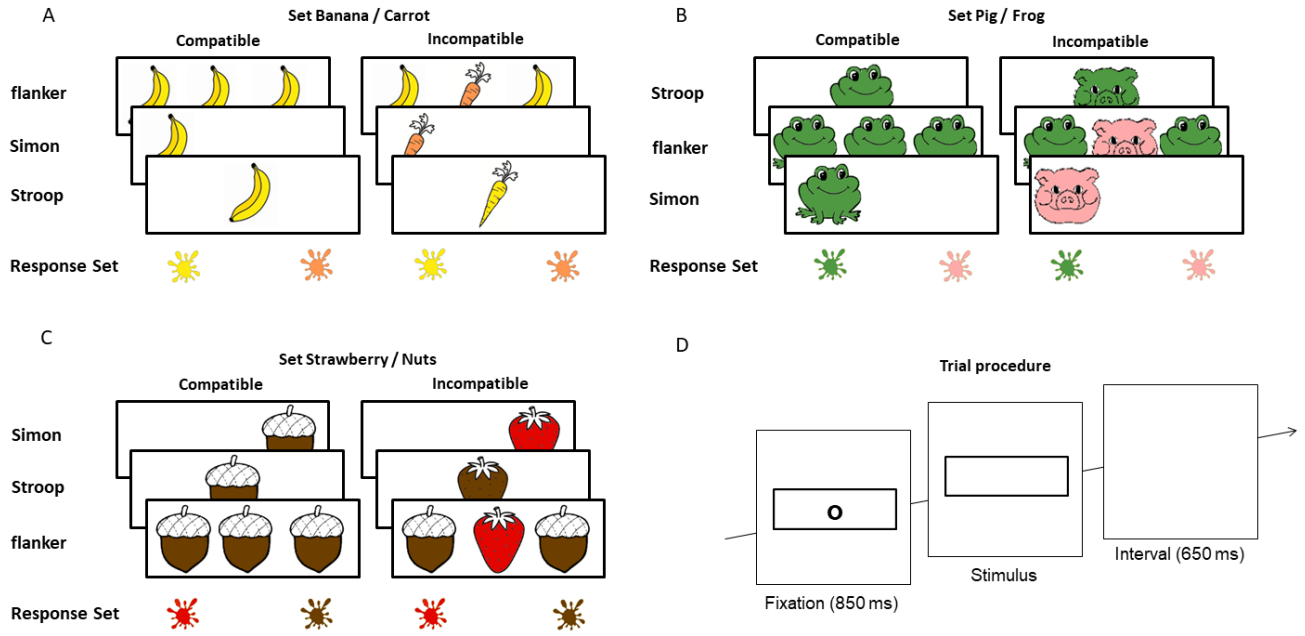

Figure 1. Illustrations of the three sets of stimuli used in each of the three tasks (A, B, and C) and of the common trial sequence (D).

a break was given between each task. The experiment lasted for approximately 40-45 minutes for younger children and 20-25 minutes for adolescents and adults.

Data processing

Participants with accuracy rates or mean response times (RTs) beyond three standard deviations from the mean of their age group in at least one of the three tasks were considered as outliers. This resulted in the exclusion of 7.3% participants (See Table 2, "N" column for the distribution of outliers by age group). Children are known to be prone to lapses of attention, leading to excessively long RTs on some trials, and prone to anticipated response, leading to excessively fast RTs. First, trials with RTs larger than three standard deviations from participant's mean RT for each trial type in each task and trials with excessively short RTs (< 300 ms for participants ranged from 5 to 8; < 250 ms for participants ranged from 9 to 14) were excluded. Second, for correct RTs analyses, only correct trials preceded by correct trials were analyzed to exclude RTs slowing typically caused by error processing, as a potential source of noise that would not be equally distributed across age groups (cf. "Correct following error" in Table **??**).

Distribution analyses

Distribution analyses were performed using the method described in Ambrosi et al. (2019). Data were first "vincentized" (Ratcliff, 1979; Vincent, 1912): the RTs were sorted in ascending order and binned in 5 classes of equal size (same number of trials). Conditional Accuracy Functions (CAFs) were plotted by computing the probability of correct responses within each bin, separately for each participant, task, and trial type. In RT distributions analyses, correct trials preceded by correct trials were first vincentized and the mean of each bin (henceforth referred to as quintiles) was computed separately for each participant, task, and trial type. Average distributions (for Accuracy and RTs analysis) were obtained by computing the mean values of quintiles by task (Simon, Stroop, and flanker), age group, and trial type (compatible and incompatible) separately.

Results

We first looked into participants' overall mean performances across the three tasks. To get a better understanding of multiple interactions, we then analyzed the mean performance on each task separately, before examining in which way the inclusion of the factor quintile may highlight the temporal dynamics of conflict processing in each task and account for the performance[1]. All ANOVAs were

[1]Considering that the factor quintile does not rely on absolute RTs but on their relative values in each age group, interactions between age and quintile are not affected by differences in response speed between age groups and highlight age-related changes in the relative dynamics of interference-control processes

Table 2

Number of Participants Included in the Analyses, Percentages of Trials Excluded From the Analyses, and Percentages of Correct Trials Following Errors as a Function of Task and Age

		Simon			Flanker			Stroop		
Group	N[a]	Too short	Too long	Correct following Error[b]	Too short	Too long	Correct following Error[b]	Too short	Too long	Correct following Error[b]
5	32	0.33% (141)	2.12% (3896)	3.78% (1209)	0.59% (124)	2.15% (4061)	3.42% (1172)	0.26% (131)	1.99% (5003)	6.02% (1527)
6	32	0.13% (170)	1.79% (247)	3.12% (968)	0.03% (272)	1.76% (2557)	2.12% (1054)	0.36% (166)	1.95% (3744)	4% (1187)
7	33	0.57% (184)	1.83% (2267)	4.89% (767)	0.51% (173)	1.74% (2520)	3.57% (808)	0.57% (176)	1.77% (4252)	6.09% (1081)
8	34	0.43% (219)	1.65% (1776)	3.58% (747)	0.52% (224)	1.9% (2068)	4.11% (841)	0.49% (244)	1.5% (2352)	5.88% (876)
9	32	0.1% (150)	1.27% (1599)	2.64% (686)	0.03% (112)	1.27% (1568)	2.25% (717)	0.03% (208)	1.73% (1968)	4.23% (918)
10	33	0.06% (200)	1.58% (1797)	2.65% (684)	0.13% (180)	1.77% (2423)	2.59% (692)	0.16% (151)	1.55% (1937)	3.72% (807)
11	32	0.39% (195)	1.6% (1253)	3.45% (564)	0%	1.3% (2489)	2.99% (604)	0.26% (182)	1.66% (1826)	4.75% (764)
12	34	0.18% (231)	1.41% (1133)	2.27% (552)	0.12% (181)	1.41% (1142)	1.9% (577)	0.21% (216)	1.62% (1395)	2.67% (698)
13	35	0.51% (166)	1.52% (918)	3.04% (522)	0.12% (240)	1.07% (989)	2.95% (530)	0.06% (201)	1.49% (1152)	4.05% (605)
14	34	0.12% (231)	1.29% (880)	3.03% (505)	0.25% (234)	1.35% (989)	2.14% (550)	0.03% (102)	1.41% (1201)	2.85% (617)
Adult	36	no	no	2.2% (456)	no	no	2% (483)	no	no	2.66% (554)
Total	367	0.28%	1.6%	3.14%	0.23%	1.57%	2.72%	0.24%	1.66%	4.24%

Note. Average RTs are given in parentheses. [a]Differences to 36 correspond to the number of outliers in the age group. [b]Percentage of correct trials following errors: They were not considered in RT analysis

conducted with the R software (R version 3.3.2) using the *ezANOVA* function of the 'ez' package (version 4.4-0, Lawrence, 2016). Degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity (Greenhouse & Geisser, 1959) where necessary (significant Mauchly's test; Mauchly, 1940); ϵ and p-value (after correction when needed) are reported for significant effects along with Partial Eta squared (η_p^2). All p values associated with post-hoc comparisons were Bonferroni-corrected.

Mean Interference Effects across Tasks

Two mixed-designed ANOVAs were computed with interference (compatible, incompatible) and task (Simon, Stroop, flanker) as within-subject factors, and age (5,6,... 14, adults, i.e. 10 age groups, overall) as a between-subject factor on RTs of correct responses following correct responses and on accuracy as dependent variables. They produced perfectly convergent evidence corresponding to improved performance with age [$F(10, 356) = 7.25, MSE = 0.018, p < .001, \eta_p^2 = .17$ on accuracy and $F(10, 356) = 85.82, MSE = 624673, p < .001, \eta_p^2 = .71$ on RTs], better performance on compatible than incompatible trials [$F(1, 356) = 456.12; MSE = 0.008, p < .001, \eta_p^2 = .56$ on accuracy and $F(1, 356) = 548.36, MSE = 16691, p < .001, \eta_p^2 = .61$ on RTs], and a task effect [$F(2, 712) = 74.43, = .941, MSE = .005, p < .001, \eta_p^2 = .17$ on accuracy, $F(2, 712) = 126.47, = .801, MSE = 148145, p < .001, \eta_p^2 = .26$ on RTs]. Planned orthogonal contrasts further evidenced longer RTs and higher error rates in the Stroop than in the two other tasks, and better performance in the Simon than flanker task (all four $t's(712) > 3.6, p < .0001$; cf. 2). There was an interaction between interference and task [$F(2, 712) = 84.53, MSE = .006, = .936, p < .001, \eta_p^2 = .19$ on accuracy and $F(2, 712) = 21.90, MSE = 18310, = .861, p < .001, \eta_p^2 = .06$ on RTs], and between interference and age [$F(10, 356) = 2.08, MSE = .008, p < .03, \eta_p^2 = .06$ on accuracy and $F(10, 356) = 9.99, MSE = 16691, p < .001, \eta_p^2 = .22$ on RTs]. Importantly, these interactions were qualified by a three-way interaction between age, interference and task [$F(20, 712) = 1.62, MSE = .006, \epsilon = .936, p = .048, \eta_p^2 = .04$ on accuracy and $F(20, 712) = 1.79, MSE = 18310, \epsilon = .861, p = .025, \eta_p^2 = .05$ on RTs] suggesting different developmental courses of interference control depending on task (see Figure 2). This complex interaction was examined through separate ANOVAs for each task, to examine more closely the development of interference control for each type of conflict. (cf. Table S1 for detailed results of these statistical analyses and Figure 2 for descriptive results).

Mean Interference Effects within each Task

In the Simon task, interference effects observed on RTs and accuracy were significant (both $p's < .001$) and not influenced by age despite the large age span (both $p's > .33$). In contrast, in the Stroop task, significant two-way interactions between interference and age were observed on both dependent variables (both $p's < .005$) pointing to a reduction of the interference effects with age. Further analyses revealed significant interference effects in all age groups (all $p's < .0001$ for accuracy and all $p's < .002$ for RTs). On the flanker task, interference effects were significant on both dependent variables (both $p's < .001$). Whereas age did not modulate interference effect when considering accuracy ($p > .65$), the Age × Interference interaction was significant when measured on RTs ($p < .001$). Interference effects on RTs were significant in all age groups (all $p's < .0001$) and revealed an overall reduction of interference effect with age

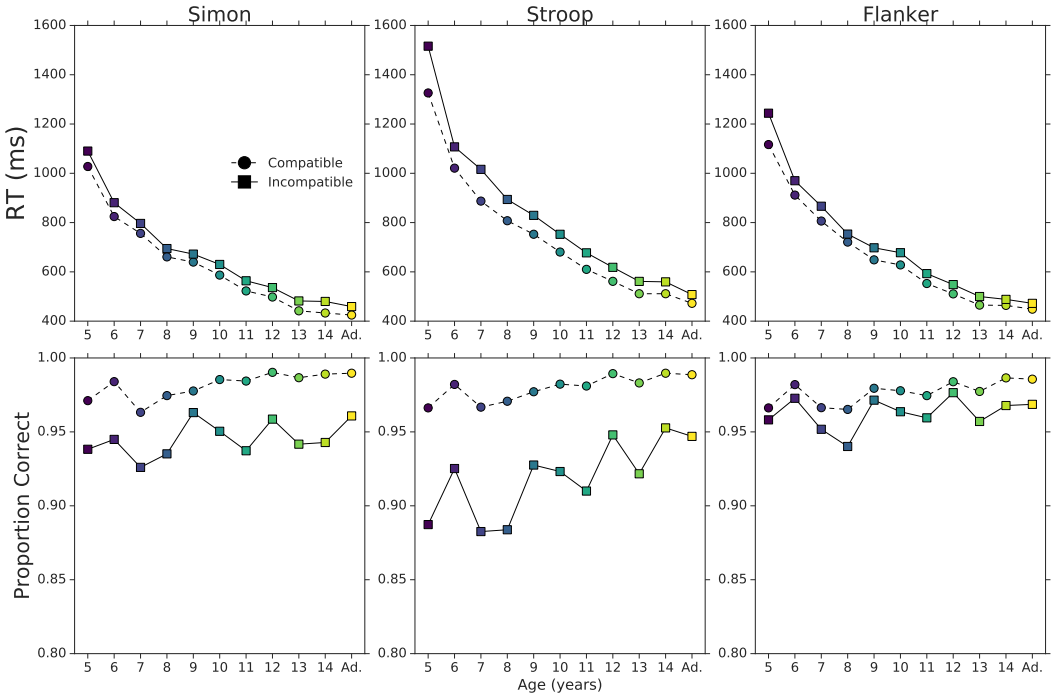

Figure 2. Interference effects as a function of tasks and age measured on accuracy and RTs. See the online article for the color version of this figure.

although not as clear-cut as in the Stroop task (see Figure 2)

Altogether, these global analyses already suggest different developmental patterns depending on the type of the conflict task. To examine the processes underlying these differences, and to address the main goal of this study, the dynamics of response activation and suppression across age groups was analyzed for each task separately.

Dynamics of Response Activation and Suppression

Simon task.

Accuracy, CAF. On accuracy, distribution analyses revealed an effect of quintile [$F(4, 1424) = 182.38, p < .001, MSE = .005, \epsilon = .583, \eta_p^2 = .34$], and a significant interaction between interference and quintile [$F(4, 1424) = 197.87, p < .001, MSE = .004, \epsilon = .606, \eta_p^2 = .36$]. Indeed, a significant interference effect was obtained only at shortest response latencies [$F(1, 356) = 328,57, p < .001, MSE = .014$ in the 1st quintile and $F(1, 356) = 30.78, p < .001, MSE = .004$ in the 2nd quintile] and disappeared at longer ones (all $p's > .22$). As such, whereas accuracy on compatible trials remained stable and near ceiling across quintiles, performance on incompatible ones revealed a drop in accuracy on the first quintiles (cf. Figure 3 and Table S2). The interaction between interference, quintile and age did not quite reach significance [$F(40, 1424) = 1.49, p = .062, MSE = .004, \epsilon = .606, \eta_p^2 = .04$]. In particular, age did not significantly modulate the interference effect on the first two quintiles [$F(10, 356) = 1.69, MSE = .014, p = .083$ in the 1st and $F(10, 356) = 1.22, MSE = .004, p = .275$ in the 2nd quintile].

RTs distributions. An ANOVA on vincentized RTs revealed a trivial effect of quintile [$F(4, 1424) = 846.54, p < .001, MSE = 25107, \epsilon = .262, \eta_p^2 = .70$] and an interaction between interference and quintile [$F(4, 1424) = 20.67, p < .001, MSE = 2932, \epsilon = .310, \eta_p^2 = .05$] (see Figure 4C). Interference effects decreased as response latencies increased to become non-significant in the last quintile (cf. Table 3). Importantly, this interaction was not qualified by age [$F(40, 1424) < 1$] (see Figures 4A and 4B).

Stroop task.

Accuracy, CAF. Analyses on accuracy distributions revealed a main effect of quintile [$F(4, 1424) = 109.09, p < .001, MSE = .007, \epsilon = .725, \eta_p^2 = .23$], a significant interaction between interference and quintile [$F(4, 1424) = 67.22, p < .001, MSE = .006, \epsilon = .743, \eta_p^2 = .16$], and a significant three-way interaction between interference, quintile and age [$F(40, 1424) = 1.59, p = .024, MSE = .006, \epsilon = .743, \eta_p^2 = .04$]. The interaction between interference and quintile was found significant from the age of 7 (cf. Table S3). In contrast, interference effect did not seem to depend on quintiles in 5- and 6-year-old children. Further analyses revealed (see also Figure 5) that although stronger for shorter latencies, interference effect remained significant up to the 5th quintile in children aged 7 to 12 (all $p's < .05$, except $p = .078$ at 8). From 13 years onwards, interference effect

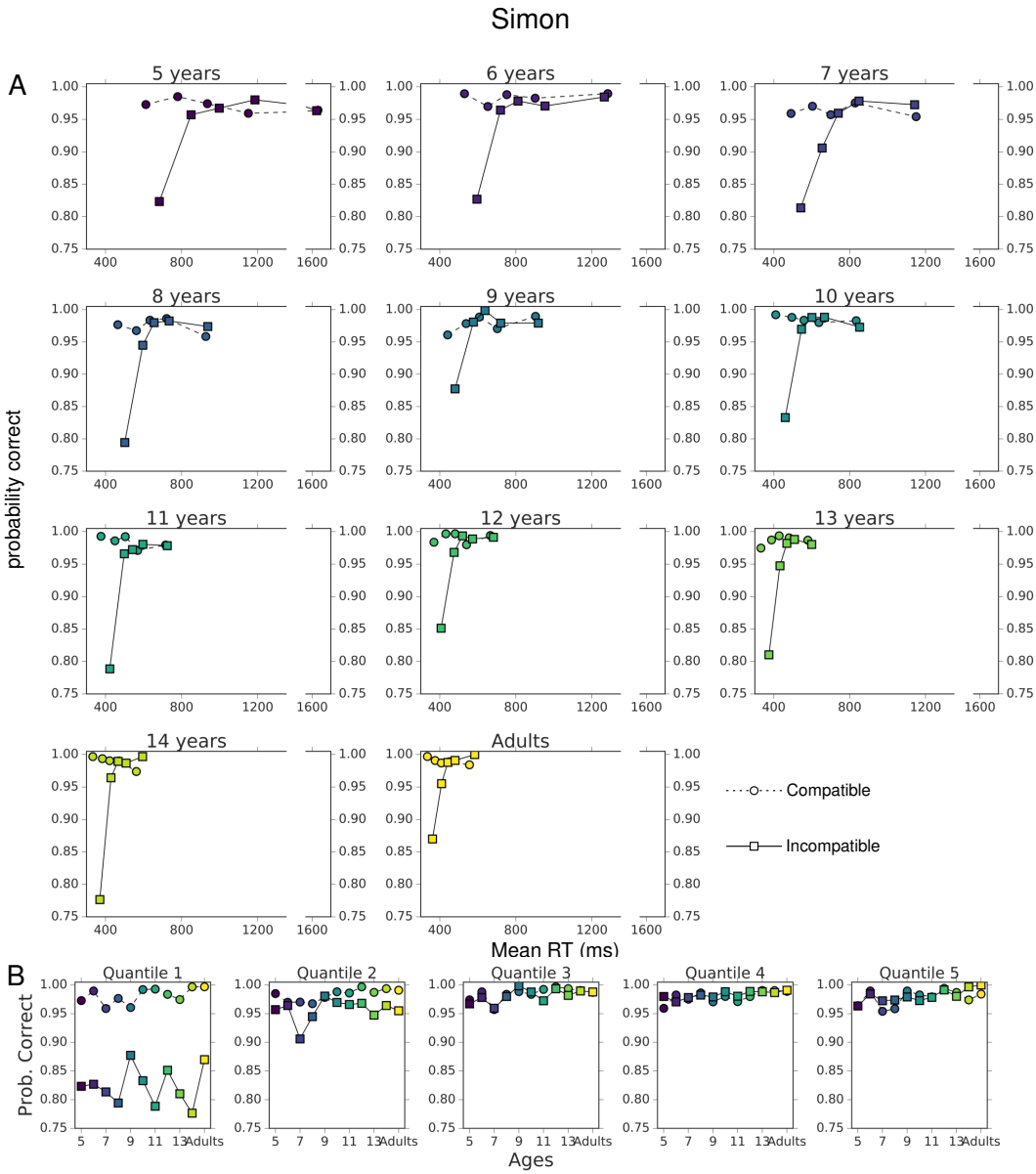

Figure 3. Simon task: Conditional accuracy functions. (A) Mean accuracy rate as a function of interference and quintile for each age group. (B) Mean accuracy rate as a function of interference and age for each quintile. See the online article for the color version of this figure.

was no more significant for longer latencies (all $p's > .12$ in the 5th quintile).

RTs distributions. The analyses of RTs distributions revealed an effect of quintile $[F(4, 1424) = 805.58, MSE = 54279, \epsilon = .27, p < .001, \eta_p^2 = .69]$ and an interaction between interference and quintile $[F(4, 1424) = 13.16, p < .001, MSE = 7929, \epsilon = .331, \eta_p^2 = .04]$ (see Figure 6C). In contrast with accuracy performance, this interaction was not significantly modulated by age $[F(40, 1424) < 1]$ (see also Figures 6A and B). As presented in Table 4, interference effect increased as response latencies increased, with a similar relative timing across quintiles from 5- to 14 years of age and in adults (except for the 5th quintile in the 6-year-olds group).

Flanker task

Accuracy, CAF. Analyses on the distributions of response accuracy, revealed a main effect of quintile $[F(4, 1424) = 52.72, p < .001, MSE = .004, \epsilon = .833, \eta_p^2 = .13]$, and an interaction between interference and quintile $[F(4, 1424) = 15.15, p < .001, MSE = .003, \epsilon =$

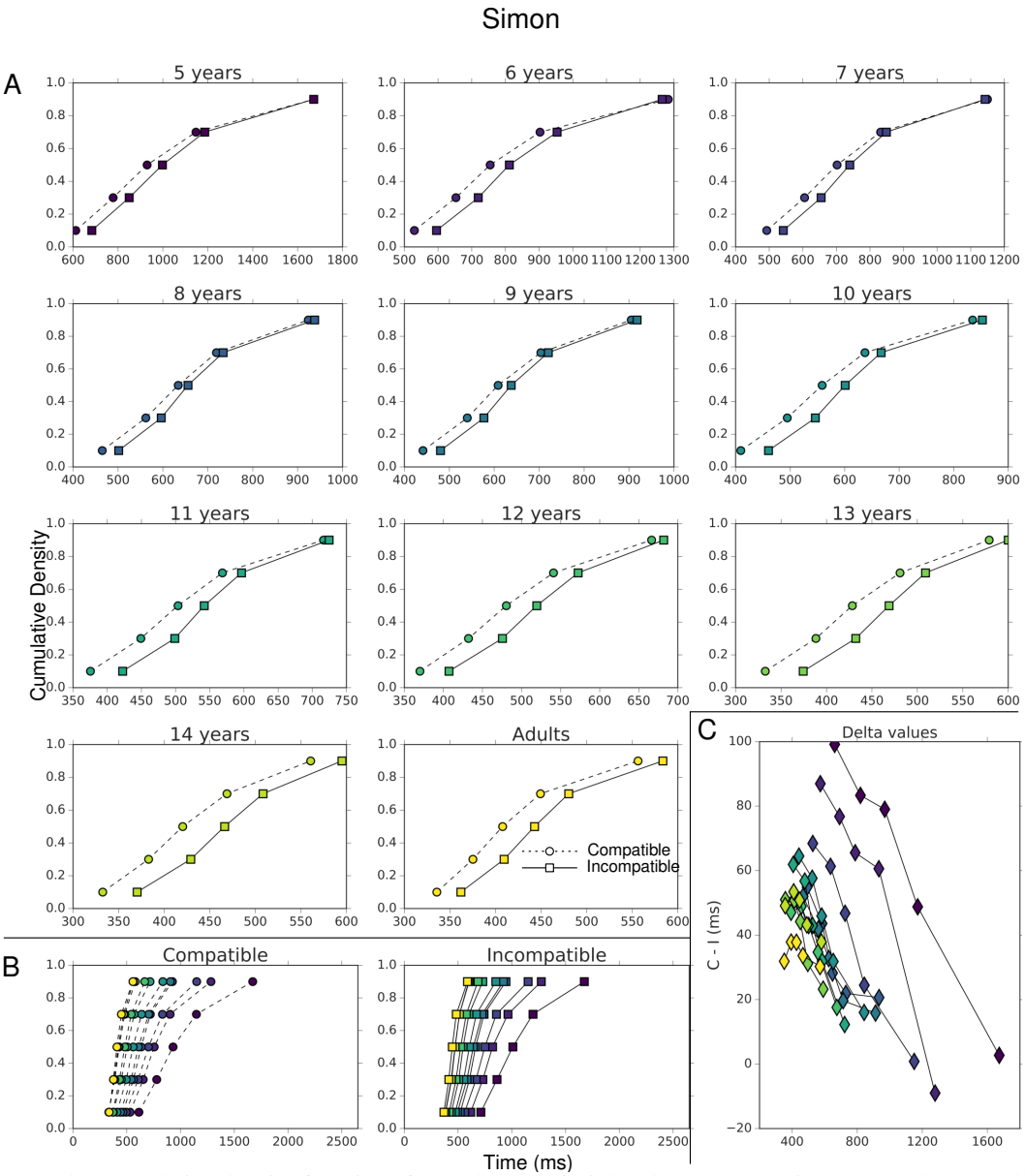

Figure 4. Simon task: Cumulative density functions for each type of trial and age group (Figure A) and across all participants (Figure B). Figure C shows the corresponding delta-plots. See the online article for the color version of this figure.

$.831, \eta_p^2 = .04$]. It corresponded to a significant interference effect only at the shortest response latencies [$F(1,356) = 51.23, MSE = .006, p < .001$ in the 1st quintile and $F(1,356) = 11.69, MSE = .003, p < .001$ in the 2nd quintile] and disappeared at longer latencies [$F(1,356) = 1.42, MSE = .002, p = .233$ in the 3rd quintile, $F(1,356) < 1$ in the 4th quintile, and $F(1,356) = 3.75, MSE = .003, p = .053$ in the 5th quintile] (cf. Figure 7, and S.M. Table 4). Importantly, a three-way interaction between interference, quintile and age [$F(40,1424) = 1.57, p = .021, MSE = .003, \epsilon = .831, \eta_p^2 = .04$] was also obtained suggesting that the temporal dynamics of interference control in the flanker task differed across age groups. The interaction between interference and quintile (cf. Table S4) was not significant in the two younger groups and in adults, it was found significant at 7, 8, 10 years and from 12 to 14 years of age. In most of these age groups, it was driven by a drop in accuracy for the fastest responses on incompatible trials (Cf. Figure 7). Patterns of CAFs are, however, less easy to characterize than in the other two tasks.

RTs distributions. The distribution analyses on RTs revealed a trivial effect of quintile [$F(4,1424) = 1171.50, MSE = 22732, \epsilon = .267, p < .001, \eta_p^2 = .77$] and a significant interaction between interference and quin-

Table 3
Simon task. Interference effect on correct RTs in each quintile and the corresponding mean interference

Quintile	Interference Effect	Interference (in ms)
1	$F(1, 356) = 770, MSE = 875, p < .001$	M = 60
2	$F(1, 356) = 770.7, MSE = 736.9, p < .001$	M = 55
3	$F(1, 356) = 323.8, MSE = 1250.3, p < .001$	M = 47
4	$F(1, 356) = 84.9, MSE = 2600.9, p < .001$	M = 35
5	$F(1, 356) = 2.94, MSE = 15625, p < .099$	M = 16

tile [$F(4, 1424) = 11.75, MSE = 2702, \epsilon = .334, p < .001, \eta_p^2 = .03$] (see Figure 8C). The interaction between Interference, Quintile and Age did not quite reach significance [$F(40, 1424) = 1.64, MSE = 2702, \epsilon = .334, p = .068, \eta_p^2 = .04$]. Notably, a similar pattern of dynamics of interference control was observed in all age groups but one, albeit with different slopes depending on age, namely, an increase of interference effects for longer latencies. (Cf. Table 5).

Discussion

Although there is a global agreement on the improvement of interference control with age across childhood (Bub et al., 2006; Davidson et al., 2006; Ridderinkhof, Van der Molen, Band, & Bashore, 1997), results are far less consistent when looked at more closely (e.g., Bossert, Kaurin, Preckel, & Frings, 2014; McDermott, Pérez-Edgar, & Fox, 2007). We suggest that this matter of fact is in part due to methodological differences which make the comparison of findings across studies partially inconclusive: different versions of each conflict task are used depending on age groups that themselves vary from study to study, together with sets of stimuli used in the tasks. In addition, in most studies, reliance on mean interference effects, commonly accepted as a proxy for control efficiency, prevents any fine-grained analysis of the underlying dynamics, impeding the detection of subtle critical age- and task-related differences in the development of interference control (see below for exceptions, Cragg, 2016; Erb & Marcovitch, 2018; Erb et al., 2018). The purpose of this study was to provide a detailed picture of the development of processes underlying interference control from 5 years up to adulthood through the investigation of the processing of three kinds of conflict. In the Simon task, conflict arises between a response feature (its laterality) and the irrelevant spatial location of the stimulus on the screen. In both the Stroop and the flanker tasks, conflict involves two dimensions of the stimuli (further differences between these two tasks are discussed below). For the very first time, this study offers versions of the three mostly used conflict tasks that revealed sensitive to interference control across a wide age range, from 5 years to young adulthood. This is an important achievement in this field of research, as typical tasks designed for non-reading children under 7 (e.g. day-night Stroop, grass-snow Stroop, or fish flanker) are usually different from those most commonly used in older children and adults, blurring the understanding of the development of processes across the entire age range. Further, we controlled for (a) sample variations by using a within-participants design for the three conflict tasks, (b) stimuli variations by counterbalancing the same three sets of stimuli across tasks and (c) nature and complexity of rules by requesting responses always based on a unique color dimension. These well-controlled settings, applied for the first time in this field of research, removed usual confounding factors and allowed us to interpret between-tasks differences in terms of nature of conflicts. Last but not least, the use of distributional analyses highlights the developmental trajectories of the dynamics of response activation and suppression that underlie the interference effects. The developmental trajectories of mean interference effects were found to differ between the three tasks. Whereas findings in the Simon task revealed mature performance pattern, suggesting adult-like interference control from 5 years onwards, findings in the Stroop task showed a much more protracted development across childhood and adolescence. A slightly less consistent reduction of the interference effect with age was obtained in the flanker task. Overall, these differences suggest the critical role of the type of conflict to overcome. Distribution analyses allowed us to explore further the processes underlying these different developmental trajectories.

Developmental Changes in the Time Courses of Response Activation/Suppression

Previous research in adults has shown both similarities and differences in the dynamics of response activation and suppression between different kinds of conflict. These similarities and differences are, to a large extent, also observed in the present data across the different age groups. As in adults, the chronometric Simon effect decreased with longer latencies (negative-going delta plot) and the Stroop and flanker effects increased for slower responses (positive-going delta plots, see Pratte et al., 2010 for a review of similar patterns in adults). This pattern was obtained in both adults and children across the whole age range. Although the time course of chronometric interference did not reveal any significant change with age in any of the three tasks, the time scale of the effect decreased drastically with age due to the increase in speed of processing across the age range. In other words, the

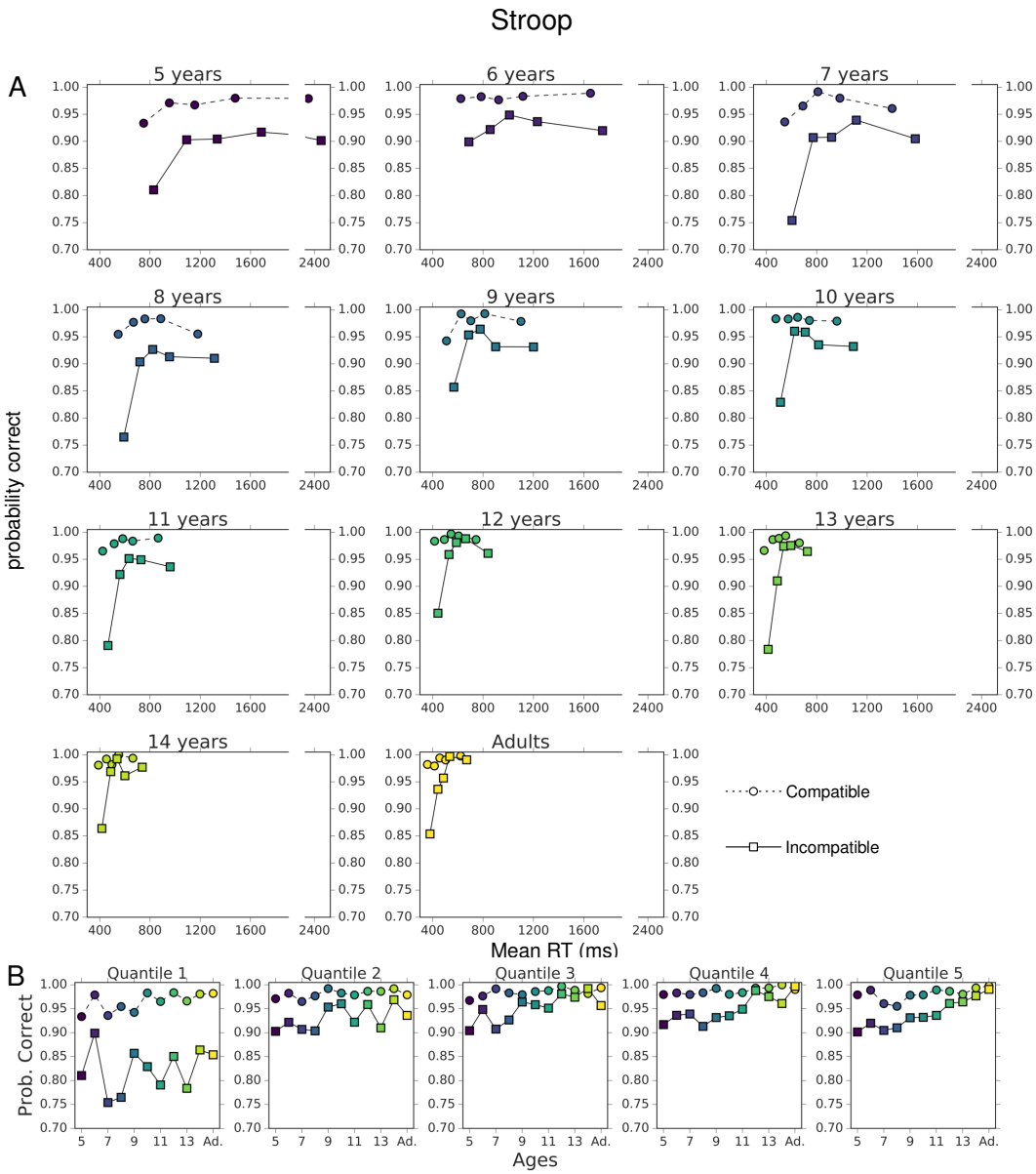

Figure 5. Stroop task: Conditional accuracy functions. (A) Mean accuracy rate as a function of interference and quintile for each age group. (B) Mean accuracy rate as a function of interference and age for each quintile. See the online article for the color version of this figure.

common typical pattern of delta plots in all age groups illustrates a position-scale invariance across all tasks. These results are in line with Ambrosi et al.'s (2019) findings that revealed an adult-like pattern in 5- and 6-year-old children for the three types of conflict. Following Ridderinkhof (2002), these results suggest that, like adults, children as young as 5 years, demonstrate weaker selective suppression of the initial response activation in the Stroop and flanker tasks than in the Simon task. The absence of developmental changes in any of the three tasks therefore suggests a mature inhibitory control in 5-year-old children that may seem at odds with the consensual view of the improved efficiency of inhibitory processes across childhood. However, interpreting delta plots as reflecting inhibitory processes has not remained unquestioned. Following Ulrich's et al. (2015) model, delta plots essentially index the dynamics (especially the duration) of the automatic activation of the response induced by the irrelevant stimulus dimension relative to the controlled response activation. Whether this duration is under the control of an active suppression mechanism or not, remains a matter of debate. Nevertheless, the invariance of delta functions in a wide age range (although less clear for the flanker task) empha-

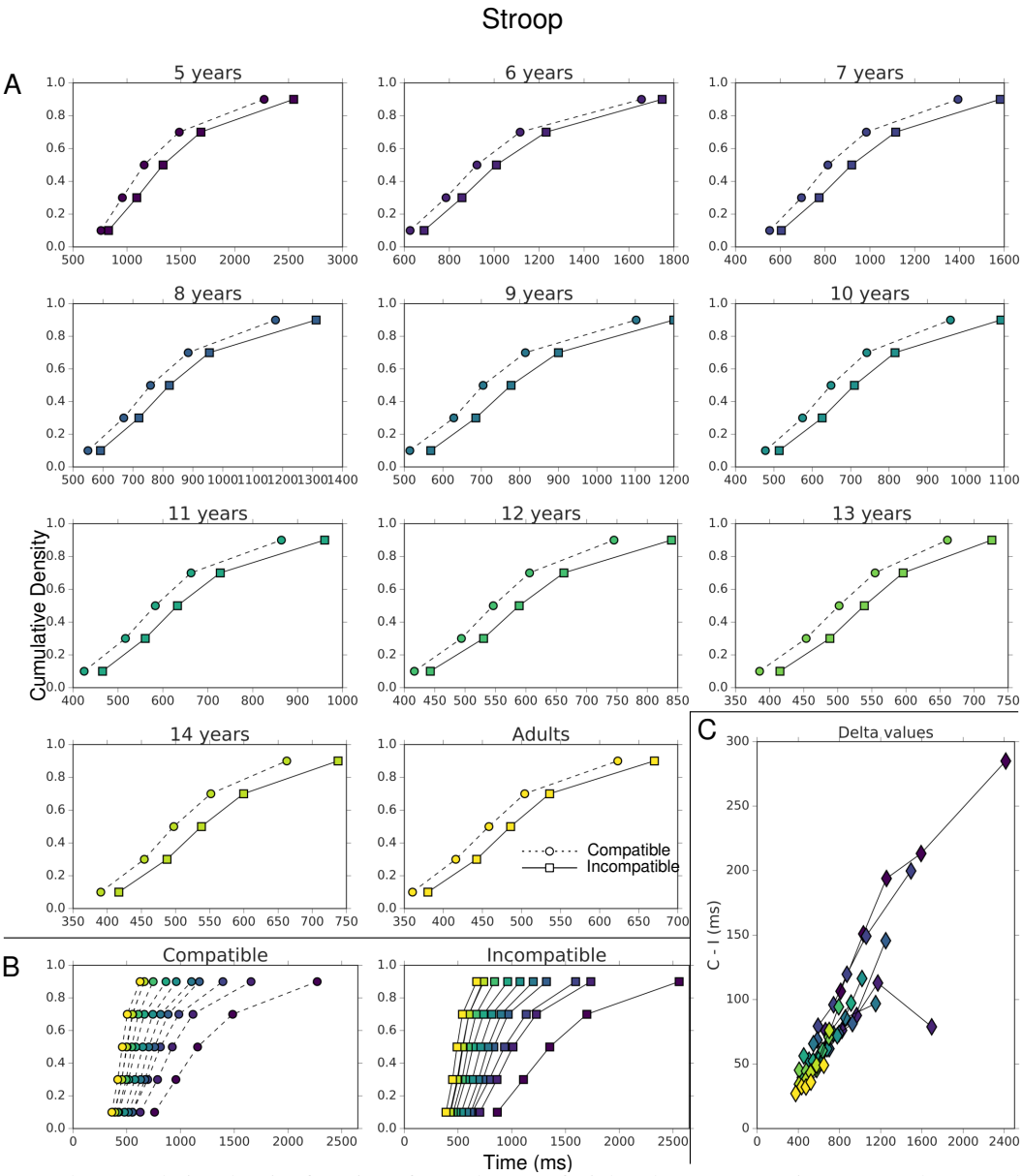

Figure 6. Stroop task: Cumulative density functions for each type of trial and age group (Figure A) and across all participants (Figure B). Figure C shows the corresponding delta-plots. See the online article for the color version of this figure.

sizes similarity in the interplay between automatic and controlled responses on correct trials across different age groups. CAFs, however, revealed more nuanced developmental patterns. In adults, CAFs in all three conflict tasks, show a drop in accuracy for shortest response latencies on incompatible trials that is rapidly caught up with longer latencies (e.g., Van den Wildenberg et al., 2010). This finding was replicated in the present group of adults but also, interestingly, in most groups of children and adolescents, although different developmental trajectories have been observed depending on tasks. Adult-like functions were obtained as early as 5 years of age in the Simon task but not before 13 in the Stroop task. Interestingly, these developmental decalages in the emergence of the mature pattern mirror the overall difficulty of tasks. In the Simon task, the initial incorrect response capture was very transient across all age groups: it had an early deleterious effect on incompatible trials which was rapidly overcome, leading to the disappearance of the Simon effect for the longest response latencies. This suggests early maturity of interference control when conflict results from the overlap between stimulus and response features (stimulus location and response side). In contrast to the Simon task, the dynamics of response activation and suppression in the flanker and Stroop tasks, in which two dimensions

Table 4
Stroop task. Interference effect on correct RTs in each quintile and the corresponding mean interference

Quintile	Interference Effect	Interference (in ms)
1	$F(1, 356) = 400.4, MSE = 1608.3, p < .001$	M = 57
2	$F(1, 356) = 341.9, MSE = 2257.3, p < .001$	M = 64
3	$F(1, 356) = 207.8, MSE = 5043, p < .001$	M = 75
4	$F(1, 356) = 116, MSE = 12521, p < .001$	M = 88
5	$F(1, 356) = 58, MSE = 44818.3, p < .001$	M = 118

of the stimulus overlap (color of target vs color of flankers in the flanker task, displayed color vs true color in the Stroop task), undergo developmental changes that share some commonalities. In the two younger age groups, there was no evidence of a reduction of the interference effect with longer response latencies, a pattern strikingly different from the one usually observed in adults. This suggests a prolonged activation of the initial automatic response that was not overcome by the activation of the controlled correct response. In older participants, the overall shape of accuracy functions differed between the two tasks. In the Stroop task, children from 7 to 12 years old showed a clear drop in accuracy for shortest response latencies on incompatible trials but their performance remained below ceiling even for the longest latencies. This indicates a late activation of the correct response that fails to counteract the early incorrect automatic activation. In contrast, adolescents from 13 years onwards and adults reached ceiling performance in longer RTs. The developmental trajectory was less consistent in the flanker task: although most age groups above the age of 6 showed a drop in accuracy for shortest response latencies on incompatible trials and a flat curve for compatible ones, this was not statistically established in adults, and 9- and 11-year-olds. Inconsistencies in the flanker task are not restricted to the present data. Bossert et al. (2014) concluded that the developmental literature on this task offers at best a blurred empirical picture of development: Some studies have suggested improvements of interference control until late childhood (e.g. Pozuelos et al., 2014; Waszak et al., 2010), whereas others have not found the age effect (Bossert et al., 2014; McDermott et al., 2017). One potential reason for such inconsistencies is the fact that most task versions used in children (including the present one) confound two sources of interference: On incompatible trials, flankers are simultaneously perceptually different from the target and call for a different response, whereas on compatible ones, they are perceptually identical to the target and prompt the same response. Hence, interference on incompatible trials may rise both at stimulus and response levels. Developmental inconsistencies within this task could then stem from different developmental trajectories of stimulus vs response interference control (Cragg, 2016). Cragg manipulated these two forms of interference in adapted versions of a flanker task. The results suggested that response interference control is already mature at the age of seven whereas stimulus interference control has a more protracted development. Indeed, the distributional pattern in the present study might result from the combination of these potentially developmentally asynchronous forms of control. Further studies applying distribution analyses in versions of the flanker task which allow for dissociating stimulus- and response-conflicts should help overcoming the current inconsistencies.

Recently Erb and colleagues (Erb & Marcovitch, 2018; Erb et al., 2018) examined another dissociation of processes that might contribute to the age-related changes in interference control. In two independent studies, using reach-tracking versions of two conflict tasks (flanker and Simon), the authors provided evidence for two processes underlying inhibitory control: A response-threshold adjustment process that corresponds to a form of global inhibition of the motor output, and a controlled selection process that increases the activation of the controlled response. These studies suggested that the controlled selection process may have a more protracted development than the response adjustment one. The present approach based on distributional analyses and the reach-tracking methodology shed complementary light on the processes contributing to the developmental changes in interference control. Yet, a bridge remains to be built between the two approaches as one examines the interplay between automatic and controlled processes while the other offers a differentiation among two controlled processes. Altogether, the present findings underscore the relevance of distributional analyses in revealing important developmental and conflict-related differences in interference control that remained hidden when considering mean interference effects as the unique measure. Further, CAFs offer an input to a recent debate in the developmental literature concerning the beneficial effect of imposing a delay on children before allowing them to respond to cognitive control tasks. Simpson, Diamond and colleagues proposed that delaying responses allows the prepotent incorrect response to dissipate, thereby enabling the correct one to reach the response threshold (Diamond, Kirkham, & Amso, 20020; Ling, Wong, & Diamond, 2016; Simpson et al. 2012). On the other hand, Barker and Munakata (2015) pointed out that most studies demonstrating a benefit of delay confounded longer imposed delays with the introduction of hints that could play a role as goal reminders. Hence, they suggested that scaffolding goal maintenance could be the key explanation (for further evi-

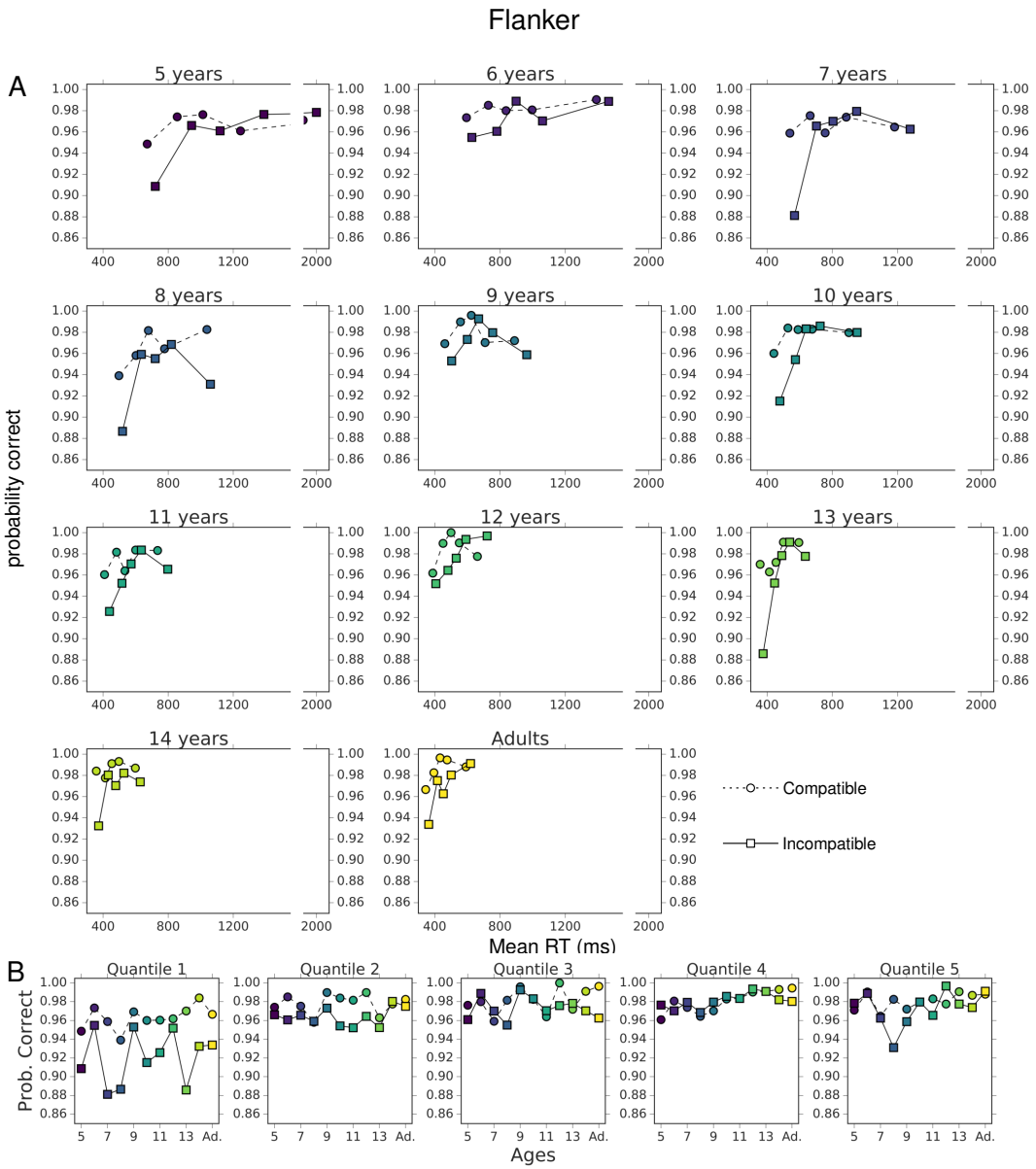

Figure 7. Flanker task: Conditional accuracy functions. (A) Mean accuracy rate as a function of interference and quintile for each age group. (B) Mean accuracy rate as a function of interference and age for each quintile. See the online article for the color version of this figure.

dence on the crucial role of goal maintenance in children's cognitive control, see Chevalier & Blaye, 2008; Marcovitch, Boseovski, & Knapp, 2007; Marcovitch, Boseovski, Knapp, & Kane, 2010; Towse, Lewis, & Knowles, 2007). By examining the time course of error rates as a function of response latencies - therefore in the lack of any external intervention likely to serve as the goal reminder – CAFs could be used to provide a critical test to decide between these two accounts. Indeed, in the present study, the contrast observed in 5- and 6-year-olds' between a mature pattern in the Simon task and the persistence of an interference effect for longer response latencies on incompatible trials of Stroop and flanker tasks, suggests that the role of goal maintenance might depend on tasks. Whereas remembering "giving the color" is sufficient in the Simon task as there is only one potential stimulus to consider – which facilitates goal maintenance – it is not specific enough for the other two tasks due to the above-mentioned overlap between their stimulus dimensions. In the flanker task, "giving the color" may lead to a different response whether it is applied to the flankers or the target and it is misleading for incompatible trials of the Stroop task where one must ignore the displayed color and give the "true" color

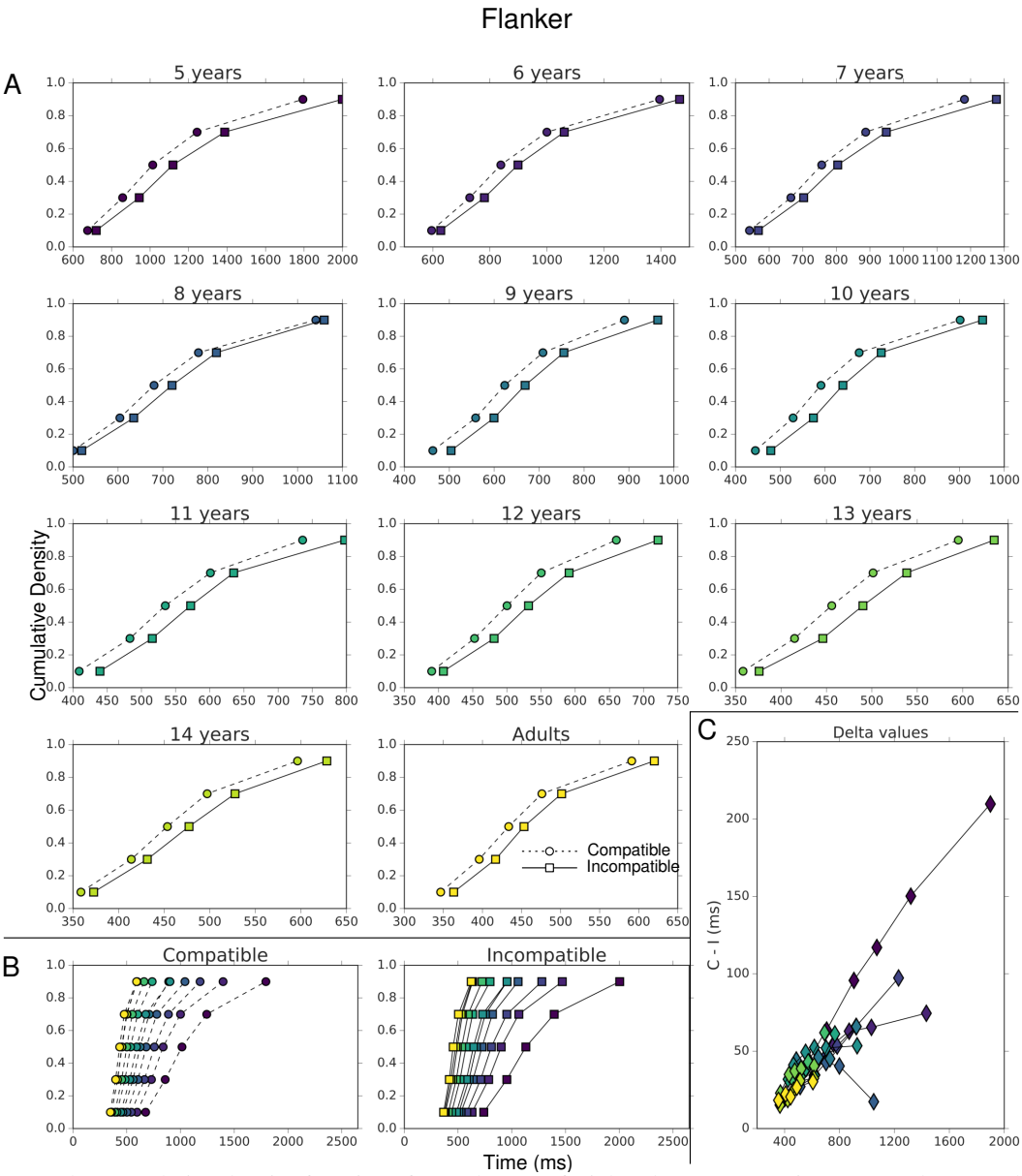

Figure 8. Stroop task: Cumulative density functions for each type of trial and age group (Figure A) and across all participants (Figure B). Figure C shows the corresponding delta-plots. See the online article for the color version of this figure.

of the target. In other words, delayed responses (i.e. longer latencies) appear sufficient to reach ceiling performance on the Simon task supporting the "passive dissipation" hypothesis. In contrast, without any goal reminder, performance remains under ceiling in these two age groups for flanker and Stroop suggesting that goal reminding may be critical for these tasks. Further studies specifically designed to address the role of this factor could benefit from distributional analyses. Additional differences between these three types of conflict, other than those related to "passive decay" vs "goal reminder", can however be at stake. In incompatible trials of the Stroop task perceptual information – the displayed color – conflicts with semantic information – the object's canonical color – that must be retrieved from long-term memory. Less automatic access to the relevant information in 5- and 6-year-olds could contribute to the lack of drop in accuracy on incompatible trials for shortest response latencies. The systematic investigation of the potential sources of inter-tasks differences should be conducted in future research by applying distributional analyses to new versions of tasks deconfounding these factors. This was beyond the scope of the present study which foremost aimed to identify the task-specific time course of automatic and controlled response-activations across development.

Table 5
Flanker task. Interference effect on correct RTs in each quintile and the corresponding mean interference

Quintile	Interference Effect	Interference (in ms)
1	$F(1,356) = 267.4, MSE = 722.8, p < .001$	M = 32
2	$F(1,356) = 378.5, MSE = 860.3, p < .001$	M = 42
3	$F(1,356) = 277.4, MSE = 1527.6, p < .001$	M = 47
4	$F(1,356) = 197.3, MSE = 2696.6, p < .001$	M = 53
5	$F(1,356) = 58.2, MSE = 14421.5, p < .001$	M = 67

Limitations

The current study presents some limitations. It is cross-sectional and forthcoming studies should test longitudinally the evidenced developmental changes on more narrow age ranges. Further, although CAFs better reveal the dynamics of incorrect response activation, as they are based on overt responses, they consider only uncorrected responses, namely errors. Two main techniques going beyond mere behavior, have proven particularly useful in revealing subliminal incorrect activations that were subsequently corrected: (a) Tracing the movement curvature towards the correct response location (Resulaj, Kiani, Wolpert, & Shadlen, 2009) in "reach tracking" versions of conflict tasks (Erb et al., 2018) revealed that, the initial movement sometimes deviates from a straightforward trajectory thereby revealing a tendency to respond to the irrelevant dimension of the stimulus. (b) In more standard "button-press" settings, recording electromyographic (EMG) activity of the muscles involved in responding (e.g. thumb muscles when responses with thumbs are required), also revealed subliminal EMG activities occurring in the hand related to the incorrect response in about 15-20 % of correctly responded trials (Eriksen, Coles, Morris, & O'Hara, 1985, Burle et al., 2002, 2014). Such "partial errors" can be coupled with distribution analysis to reveal with better precision the dynamics of incorrect response activations and offer a more direct measure of response capture (Wildenberg et al., 2010). They also allow for studying the efficiency of the subsequent suppression, by computing a "correction ratio", which indicates the number of corrected incorrect response activations (Burle et al., 2002). Since EMG recording is technically doable in children (Smigasiewicz et al., 2020), running distribution analysis on partial errors, would be a promising way to take a new step in understanding the developmental aspects of the dynamics of incorrect response selection.

Conclusion

To our knowledge, the present study provides a unique insight to the development of interference control across three conflict tasks and a wide age range extending from preschoolers upon to young adults. Beyond evidencing different developmental trajectories of the mean interference effect depending on the type of conflict to process, it highlights the value of distribution analyses as a sensitive tool to investigate the dynamics of the underlying processes across age groups and tasks. Notably, such analyses can be applied to any dataset (already collected or to be collected) obtained with conflict tasks. While the analysis of correct response latencies distribution did not show any developmental change, the accuracy rates as a function of response latencies (CAFs) revealed developmental conflict-dependent differences. Although this approach still leaves open the debate of the specific factors that account for the differences observed, it offers a proof of concept for the feasibility of their use in children, and the value of in-depth dynamic analyses of potentially distinct developmental trajectories of the processes underlying interference control, within- and between complex tasks. By lifting the veil on the time course of interference effects across age groups and conflict tasks, distribution analyses provide new constraints on potential developmental models of conflict processing.

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