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# Dissociating distractor inhibition and episodic retrieval processes in children: No evidence for developmental deficits

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### ABSTRACT

It is often assumed that children show reduced or absent inhibition of distracting material due to pending cognitive maturation, although empirical findings do not provide strong support for the idea of an “inhibitory deficit” in children. Most of this evidence, however, is based on findings from the negative priming paradigm, which confounds distractor inhibition and episodic retrieval processes. To resolve this confound, we adopted a sequential distractor repetition paradigm of Giesen, Frings, and Rothermund (2012), which provides independent estimates of distractor inhibition and episodic retrieval processes. Children (aged 7–9 years) and young adults (aged 18–29 years) identified centrally presented target fruit stimuli among two flanking distractor fruits that were always response incompatible. Children showed both reliable distractor inhibition effects as well as robust episodic retrieval effects of distractor–response bindings. Age group comparisons suggest that processes of distractor inhibition and episodic retrieval are already present and functionally intact in children and are comparable to those of young adults. The current findings highlight that the sequential distractor repetition paradigm of Giesen et al. (2012) is a versatile tool to investigate distractor inhibition and episodic retrieval separately and in an unbiased way and is also of merit for the examination of age differences with regard to these processes.

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## Introduction

Processes of selective attention are of vital importance for our everyday functioning. They empower us to attend and respond to goal- or task-relevant information and to ignore distracting or interfering information. Selective attentional processes (i.e., focusing on task-relevant information and inhibition of task-irrelevant, distracting information) reflect a central aspect of top-down behavior control (Tipper, 1992). Hence, their development and change across the life span is a major theme in scientific research. In particular, the development of one core feature of selective attention, namely inhibition of distracting information, is assumed to follow a “last in, first out” principle (Raz, 2000). It is often assumed that distractor inhibition is a product of cognitive maturation and, therefore, is fully developed only during late adolescence or young adulthood (e.g., Dempster, 1992; Harnishfeger, 1995; van der Molen, 2000). Furthermore, it is considered as one of the first abilities that deteriorate during old age, signaling cognitive decline (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). As a consequence of this proposed curvilinear (inverse U-shaped) relationship between aging and inhibition abilities, both children and older adults are assumed to show inhibitory deficits, that is, reduced or absent inhibition of distracting material. This in turn causes interference in working memory and broadly affects cognitive performance in those age groups.

Empirical support for these theoretical claims of age group differences in distractor inhibition, however, is mixed and heterogeneous. The situation is particularly dramatic for the question of whether children show inhibitory deficits or not. To date, the claim of reduced distractor inhibition in children (aged 7 or 8 years) is supported by only one study (Tipper, Bourque, Anderson, & Brehaut, 1989), whereas a range of other more recent studies yielded consistent evidence for intact distractor inhibition in children of comparable or even younger ages (e.g., covering an age range of 6–11 years [Frings, Feix, Röthig, Brüser, & Junge, 2007; Simone & McCormick, 1999] or of 5–12 years [Pritchard & Neumann, 2004, 2009]). At first glance, the gap between theory and empirical findings seems resolved given that the majority of findings argue against an inhibitory deficit in children. However, on a closer look, things might not be so simple. That is because all of the above-mentioned evidence on (intact or deficit) distractor inhibition in children is based on findings from the negative priming paradigm (we provide a more extensive discussion of age differences that were obtained with other paradigms relating to interference and cognitive control in the General Discussion). Negative priming refers to the observation that performance is impaired (i.e., slower and/or more error prone) if a to-be-ignored distractor stimulus from the previous (prime) trial is presented as the target stimulus in the current (probe) trial. Initially, this was believed to be due to inhibition of the prime distractor that persisted to the probe trial (Tipper, 1985). To date, however, the negative priming paradigm is known to confound inhibition and episodic retrieval processes (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; Neill, Valdes, Terry, & Gorfein, 1992; for a recent review on negative priming, see Frings, Schneider, & Fox, 2015). In particular, negative priming effects can result not only from distractor inhibition but also from an automatic retrieval of episodic bindings between the prime distractor and the response that was executed during the prime trial. Repeating the distractor as target stimulus in the probe trial will retrieve the associated response from memory. Because the retrieved prime response is inappropriate in the probe, probe performance is impaired (Rothermund, Wentura, & De Houwer, 2005; see also Mayr & Buchner, 2006). Thus, negative priming is not a process-pure indicator of distractor inhibition but rather may reflect two completely different underlying processes. By implication, therefore, the presence of a negative priming effect cannot be taken as an indicator of intact distractor inhibition, nor can the lack of age differences in negative priming effects be taken as evidence for comparable levels of inhibitory functioning. For instance, a child could suffer from deficient distractor inhibition but still show a reliable negative priming effect that results from intact episodic binding and retrieval processes.

Recently, Giesen, Frings, and Rothermund (2012) introduced a distractor repetition paradigm that (a) allows dissociating processes of distractor inhibition and episodic retrieval processes within the very same task and (b) yields independent estimates of both processes. The paradigm works as follows. Participants see letter triplets (e.g., JKL) and need to identify the central target letter across a

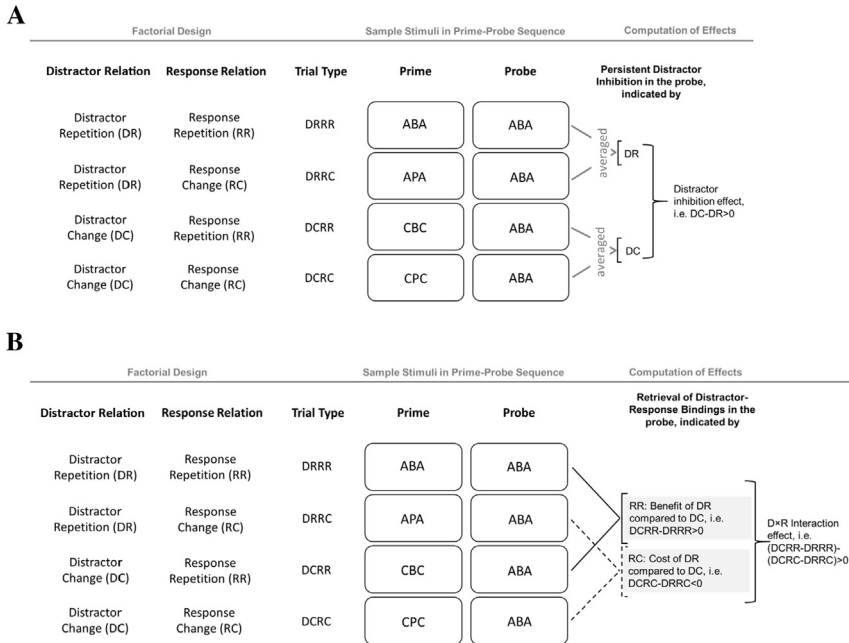
prime/probe trial sequence. In this task, flanking distractor letters need to be ignored. According to prominent inhibition accounts (e.g., [Houghton & Tipper, 1994](#)), to-be-ignored distractors should become inhibited during the prime trial. Because inhibition is assumed to persist for some time, it can be measured by repeating the prime distractor as distractor in the probe (distractor-to-distractor repetition). As a consequence, selection of the probe target should be *easier* in sequences with distractor repetition because the probe distractor is still inhibited compared with sequences with probe distractor change ([Frings & Wühr, 2007](#); [Neumann & DeSchepper, 1991](#); [Yashar & Lamy, 2010](#)). Thus, distractor inhibition is reflected in better performance in distractor repetition compared with distractor change probes (in statistical terms, this corresponds to a main effect of distractor relation; see [Fig. 1A](#)). Importantly, episodic binding and retrieval processes can be measured within the very same task by manipulating the response relation independently from the distractor relation across prime and probe trials. The idea is that the prime distractor becomes associated with the response that was executed during the prime trial in an episodic distractor–response binding in memory ([Rothermund et al., 2005](#); see also [Frings, Rothermund, & Wentura, 2007](#); [Giesen & Rothermund, 2014](#); [Giesen & Rothermund, 2015, 2016](#); [Henson, Eckstein, Waszak, Frings, & Horner, 2014](#); [Mayr & Buchner, 2006](#); [Mayr, Buchner, & Dentale, 2009](#)). Repeating the distractor in the probe then reactivates and retrieves the previously formed distractor–response binding, which affects probe performance. Compared with sequences with distractor change, distractor repetition produces (a) performance *benefits* in sequences with response repetition (because the retrieved prime response is appropriate and facilitates probe performance) but produces (b) performance *costs* in sequences with response change (because the retrieved prime response is inappropriate and impedes probe performance). In other words, episodic retrieval of distractor–response bindings is indicated by an interaction between distractor relation and response relation (see [Fig. 1B](#)).

To demonstrate that distractor inhibition and episodic retrieval processes can be independently assessed within their task, [Giesen et al. \(2012\)](#) manipulated whether distractors were incompatible or neutral with regard to the to-be-executed target response. Whereas the latter were not assigned to any response, the former were mapped to the response keys of the task and, thus, caused interference during response selection ([Eriksen & Eriksen, 1974](#)). Assuming that distractor inhibition is a function of response interference, response-incompatible distractors should receive stronger inhibition than neutral distractors. In line with this prediction, simple distractor repetition benefits indicating distractor inhibition were always stronger for incompatible distractors compared with neutral distractors in two experiments. However, [Giesen et al. \(2012\)](#) observed no differences in episodic retrieval of distractor–response bindings between neutral and response-incompatible distractors. This indicates that stronger inhibition of response-incompatible distractors did not prevent them from becoming bound to the executed prime response and from being retrieved on a later occasion. On a more general level, this shows that processes of distractor inhibition and episodic retrieval processes are functionally independent and can be experimentally dissociated within the very same paradigm.

With respect to the current study, it is particularly noteworthy that the sequential distractor repetition paradigm is of merit to investigate developmental or age-related changes in distractor inhibition and episodic retrieval processes. Only recently, [Giesen, Eberhard, and Rothermund \(2015\)](#) employed the paradigm of [Giesen et al. \(2012\)](#) to investigate age-related differences in distractor inhibition and episodic retrieval processes. Older adults (young-old: 60–64 years; old-old: 65–78 years) and younger adults (18–27 years) identified visually presented target letters among flanking distractors. Distractors were always response incompatible. Results showed that distractor inhibition was generally intact even in older adults, who showed reliable benefits in distractor repetition compared with distractor change probes. However, the older subgroup of participants (aged 65+ years) indeed showed an inhibitory deficit, indicated by a significant *reduction* in distractor repetition benefits, compared with a subgroup of young-old adults. In turn, no age differences emerged for episodic binding and retrieval processes, which were functionally intact, even in old age.

### *Aims of the current study*

Against this background, the current study aimed to investigate whether children indeed suffer from inhibitory deficits or not. We focused on children in their second school grade (aged 7–9 years),



**Fig. 1.** Factorial design, schematic sample stimuli for prime/probe sequences, and computation of effects in Experiments 1 and 2. Letters refer to the respective fruit pictures that were used in the task (pictures cannot be printed here for reasons of copyright interests): A, apple; P, pear; B, banana; C, cherry. (A) Distractor inhibition effects were computed as the difference of probe trials with distractor change (DC) minus probe trials with distractor repetition (DR), averaged across response relation. (B) Episodic retrieval effects of distractor–response bindings [computed from Distractor Relation  $\times$  Response Relation interaction effects in the probe:  $(DCRR-DRRR) - (DCRC-DRRC)$ ].

meaning that the children assessed in our study came from the same age range as in the study by Tipper et al. (1989), which yielded evidence for inhibitory deficits in children. We adopted the distractor repetition paradigm of Giesen et al. (2012, Experiment 1) to obtain unbiased and independent measures of distractor inhibition and episodic retrieval processes in children and compared their respective performance with that of young adults (aged 18–28 years). To create a version of the paradigm that is suitable for children, we introduced the following modifications to the task. First, we used colored paintings of different fruits instead of letters as stimuli in the flanker task. Exchanging the letters eliminates possible age differences in performance that are due to differential familiarity with the alphabet and should also make the task more appealing for children. Second, whereas in both former studies (Giesen et al., 2015, 2012) stimulus triplets were presented at varying and unpredictable locations on the screen across trials, which introduces spatial uncertainty and reduces spatial selection of target stimuli, stimulus triplets now appeared at a constant central position. This was done to make the task easier for children. Third, to reduce the duration of the experiment, trials were now presented in a successive stream where each trial simultaneously served as prime (for the subsequent trial) and as probe (for the previous trial). Apart from these changes, the experimental design corresponds to that of Giesen et al. (2012, Experiment 1). Participants identified a central fruit that was flanked by two identical distractor fruits. To maximize the necessity of distractor inhibition, distractors were always response incompatible to targets. The factors distractor relation (repetition vs. change) and response relation (repetition vs. change) across subsequent trials were manipulated independently within participants. Both children and young adults were then tested with this modified paradigm in Experiment 1, whereas only young adults were tested in a follow-up study (Experiment 2; see below). Experiment 1 tested the following predictions. First, if children indeed suffer from inhibitory

**Table 1**

Hypotheses and corresponding statistical tests in Experiment 1.

Hypothesis	Statistical test
H1: Distractor inhibition effects are smaller for children compared with young adults	Distractor Relation $\times$ Age Group interaction
H2: Episodic binding and retrieval effects should not differ between children and young adults	No Distractor Relation $\times$ Response Relation $\times$ Age Group interaction

deficits, distractor inhibition effects should be smaller for children compared with young adults. Second, we expected that episodic binding and retrieval processes should be intact already in children and should not differ from those of young adults. [Table 1](#) summarizes these hypotheses and relates them to the corresponding statistical tests.

## Experiment 1

### Method

#### Participants

The child sample consisted of 41 children (22 girls;  $M_{\text{age}} = 7.6$  years, range = 7–9) attending the second grade at an elementary school in Jena, Germany. Participation was voluntary. Beforehand, written consent to take part in this study was given by their parents, the school's principal, and the regional supervisory school authority. Two children were tested simultaneously in a quiet room provided by the school. Experimental sessions lasted 15–20 min for children, who received sweets as rewards for their participation. The young adult sample consisted of 40 students (20 women;  $M_{\text{age}} = 21.3$  years, range = 18–28) of Friedrich Schiller University (FSU) Jena, who participated voluntarily and gave their verbal consent prior to taking part in the study. Up to 6 participants were tested simultaneously in our campus lab (seated in individual cubicles). Experimental sessions lasted 10 min for young adults, who received 1 euro for their participation and a chocolate bar as an extra reward if they made less than 15% errors in the flanker task. Ethical approval of this study was granted by a hearing at the Department of Psychology and by the regional supervisory school authority.

#### Apparatus, stimuli, and tasks

Both the adult and child samples completed a child-oriented version of the flanker task used by [Giesen et al. \(2012, Experiment 1\)](#), programmed with E-Prime 2.0. Four small colored fruit paintings (apple, pear, banana, and cherry) served as stimuli in the task. Stimulus size approximated  $30 \times 30$  pixels or  $1.15 \times 1.15$  degrees of visual angle (with slight variations among the four stimuli due to differences in characteristic fruit shapes). Stimuli were arranged in triplets, with a target stimulus in the middle that was flanked by two identical distractor stimuli, one on each side (visual angle of full arrangement:  $1.15$  degrees vertically  $\times$   $3.78$  degrees horizontally). Stimulus triplets were presented centrally on a white background of a 19-inch flat screen. Distractors were always response incompatible to target stimuli. Each fruit was mapped to one of four response keys (marked by the fruit picture taped above the respective key) on a response box, connected to the computer via the parallel port. Participants placed their left middle and index fingers on the “apple” and “pear” keys and placed their right middle and index fingers on the “banana” and “cherry” keys. A fifth key was labeled with “Los” (“go”) and served to start the trial (operated via left or right thumb press). For each trial, participants' task was to identify the target stimulus by pressing the corresponding key on the response box. Reaction times (RTs) and accuracy of responses were recorded.

To control for cognitive functioning across the different age samples, all participants performed a short measure of processing speed that served as a proxy for fluid intelligence (color-naming task, e.g., [Kray, Karbach, & Blaye, 2012](#)). In this test, participants needed to assign four different colors to four different, colorless geometric shapes. Correct color–symbol pairings were indicated by a template (yellow circle, blue cross, red triangle, and green square). Participants were pressed for time and needed to correctly name as many colors as possible for the depicted colorless shapes within 45 s. Not surprisingly, and in agreement with standard cohort differences, children had significantly lower

scores on the processing speed measure and named fewer colors correctly than the student sample (see Table 2).

### Design

The experiment comprised a mixed  $2 \times 2 \times 2$  design with the two independent within-participant factors distractor relation and response relation and the between-participant factor age group (children vs. young adults). Distractor relation was manipulated by repeating or changing the distractor from trial<sub>n</sub> to trial<sub>n+1</sub> (25% distractor repetition [DR]; 75% distractor change [DC]). Response relation was manipulated by requiring the same or a different response from trial<sub>n</sub> to trial<sub>n+1</sub> (25% response repetition [RR]; 75% response change [RC]). Repeating the target (i.e., the response) and the distractor in 25% of all trial sequences corresponds exactly to chance for a task that contains four different stimuli. This renders the probe trials completely unpredictable on the basis of the prime trials and allowed us to eliminate any influence of expectations or response preparation on the results. Being able to rule out strategic processes is vital for our paradigm because it is a prerequisite to interpret the resulting effects and possible age group differences unambiguously in terms of inhibition and episodic retrieval processes. The factorial design, therefore, consisted of 16 DRRR, 48 DCRR, 48 DRRC, and 144 DCRC trials (cf. Fig. 1). Probe RT served as the dependent variable of primary interest, but probe error rates were also analyzed.

### Procedure

The experimental session started with the administration of the color-naming task by the experimenter, followed by the flanker task on the computer. Children were instructed verbally and were asked to help the experimenter sort different fruits. For young adults, instructions for the flanker task were given on the screen. Participants were informed that on each trial, a stimulus triplet would appear centrally on the screen. Their task was to identify the fruit in the middle by pressing the corresponding key on the response box. The flanking fruits should be ignored. Participants were asked to respond as fast and accurately as possible. Two practice blocks (with 10 and 24 trials for young adults and children, respectively) followed the instructions. In the first practice block, the mapping of stimuli to responses was trained. Thus, only a target stimulus (without flanking distractors) was presented. In the second practice block, stimulus triplets were presented. During both practice blocks, participants received performance feedback (presented for 2000 ms); correct responses were followed by a green smiley face, and incorrect responses were followed by a red grumpy face. In addition, very slow correct responses (children: RT > 3000 ms; young adults: RT > 2000 ms) were followed by a red grumpy face and the text “zu langsam” (“too slow”); this speed feedback was provided only in the second practice block (i.e., when participants were sufficiently familiarized with the response mapping). In principle, practice of the flanker task was repeated once if participants made 40% or more errors or had 40% or more slow responses. However, none of the participants needed to repeat practice. After successful completion of the practice blocks, the flanker task started, consisting of two blocks with one filler trial and 128 experimental trials, separated by a small break. Each trial started with a fixation cross (500 ms), followed by the stimulus triplet that remained on screen until a response was given. Then, the next trial started. Experimental trials were presented randomly with respect to the factorial design and with the constraints that (a) in each trial targets and distractors were always different (i.e., non-identical), (b) targets of trial<sub>n</sub> were never repeated as distractors in trial<sub>n+1</sub>, and (c) distractors in trial<sub>n</sub> were never repeated as targets in trial<sub>n+1</sub> (cf. Giesen et al., 2012, Experiment 1). Within each block, all trials were successively presented in a continuous series, with each trial simultaneously serving as probe for the previous trial and as prime for the subsequent trial. The first trial of each block, therefore, served as filler and was not analyzed. After the experiment, participants were thanked, rewarded, and debriefed.

### Results

#### Data reduction

Trials with erroneous responses in the prime and/or probe (children: 8.2%; young adults: 11.3%) and RT outlier values (i.e., RTs < 300 ms or > 1.5 interquartile ranges above the third quartile of the

**Table 2**

Means (and standard deviations) of log-transformed and untransformed probe RT and probe error rates for the factorial design of Experiments 1 and 2.

Study	Age group	Color-naming scores (number correct)	Distractor relation	Log-transformed probe RT		Probe RT (ms)		% Probe errors	
				Response relation		Response relation		Response relation	
				RR	RC	RR	RC	RR	RC
Experiment 1	Children (7–9 years), <i>n</i> = 41	31 <sub>a</sub> (7)	DR	6.64 (0.2)	6.96 (0.2)	817 (192)	1102 (173)	1.4 (2.6)	5.0 (3.9)
			DC	6.70 (0.2)	6.96 (0.2)	866 (175)	1113 (179)	2.9 (3.1)	4.9 (4.1)
			DI effect	0.03 [0.01]		30 [8.1]		0.7 [0.4]	
			ΔDC – DR	0.06 [0.01]	0.00 [0.01]	49 [10.8]	11 [10.4]	1.5 [0.5]	–0.1 [0.5]
			D × R interaction effect	0.06 [0.01]		38 [13.7]		1.6 [0.8]	
	Young adults (18–28 years), <i>n</i> = 40	48 <sub>b</sub> (8)	DR	6.10 (0.1)	6.38 (0.1)	459 (53)	606 (77)	2.7 (4.2)	7.3 (6.0)
			DC	6.12 (0.1)	6.38 (0.1)	469 (51)	605 (83)	2.9 (2.8)	6.7 (4.5)
			DI effect	0.01 [0.01]		4 [3.9]		–0.2 [0.5]	
			ΔDC – DR	0.02 [0.01]	0.00 [0.01]	10 [5.2]	–1 [5.1]	0.2 [0.7]	–0.6 [0.7]
			D × R interaction effect	0.02 [0.01]		11 [6.7]		0.8 [0.9]	
Experiment 2	Young adults (19–29 years), <i>n</i> = 40	47 <sub>b</sub> (10)	DR	6.13 (0.1)	6.40 (0.1)	472 (56)	618 (76)	1.6 (3.1)	7.1 (5.1)
			DC	6.17 (0.1)	6.42 (0.1)	491 (52)	629 (79)	2.5 (2.7)	6.4 (4.1)
			DI effect	0.03 [0.01]		15 [3.03]		0.1 [0.4]	
			ΔDC – DR	0.04 [0.01]	0.02 [0.00]	19 [4.9]	11 [2.9]	0.9 [0.6]	–0.7 [0.5]
			D × R interaction effect	0.02 [0.01]		8 [5.4]		1.6 [0.8]	

*Note.* Color-naming test scores with different subscripts differ at  $p < .001$ . RT, reaction time; DR, distractor repetition; DC, distractor change; RR, response repetition; RC, response change. DI effect, distractor inhibition effect, computed as the difference between DC and DR, averaged across response relation: DI effects =  $[(DCRR + DCRC) - (DRRR + DRRC)]/2$ . Positive values reflect probe performance benefits due to repeating a persistently inhibited prime distractor. D × R interaction effect: Distractor Relation × Response Relation interaction, indicating episodic retrieval of distractor–response bindings. Interaction effects were computed as the difference in distractor repetition effects (DC – DR) between the RR and RC conditions: D × R retrieval effect =  $(DCRR - DRRR) - (DCRC - DRRC)$ . Positive values indicate interaction effects that conform with the expected effects due to distractor-based retrieval of previous responses (i.e., facilitation for response repetition sequences and interference for response change sequences). Values in parentheses represent standard deviations. Values in squared brackets represent standard errors.



individual RT distribution; Tukey, 1977; children: 4.1%; young adults: 4.2%) were discarded. Table 2 provides mean probe RTs and error rates.

### Logarithmic transformations of probe RT

To compare probe RTs of the different age groups in a joint analysis, we followed the recommendations of Pritchard and Neumann (2009). Probe RTs were log transformed to control for age group differences that are due to slowed processing in the child sample. We then computed means of the log-transformed probe RTs for every condition of the factorial design and separately for each participant (for ease of interpretation, however, we report untransformed probe RTs in the tables and in the text; see Table 2).

### Probe performance

We performed a 2 (Distractor Relation: repetition vs. change)  $\times$  2 (Response Relation: repetition vs. change)  $\times$  2 (Age Group: children vs. young adults) mixed-model analysis of variance (ANOVA) on mean log-transformed probe RTs and mean probe error rates. See Table 3 for global ANOVA results. Main hypotheses and corresponding statistical tests for Experiment 1 are presented in Table 1. Before presenting results (descriptive and statistical tests) for distractor inhibition and episodic retrieval effects, we briefly report results for additional main effects unrelated to the effects of interest.

In detail, children on average responded slower but more accurately ( $M = 975$  ms and  $M = 3.5\%$ , respectively) than young adults ( $M = 535$  ms and  $M = 4.9\%$ ), reflected in main effects of age group for RTs and errors. Furthermore, performance was overall faster and more accurate for sequences with response repetition ( $M = 653$  ms and  $M = 2.5\%$ ) than with response change ( $M = 857$  ms and  $M = 6.0\%$ ), indicated by a main effect of response relation for both RTs and error rates (see Table 2).

**Distractor inhibition effects.** Analyses further revealed that probe performance was generally faster for sequences with distractor repetition ( $M = 746$  ms) compared with distractor change ( $M = 763$  ms). Statistically, this was indicated by a main effect of distractor relation for RTs (not for errors) that reflects a pattern of distractor inhibition. Importantly, this main effect was qualified by age group (i.e., the interaction of distractor relation and age group was significant for RTs but not for errors), meaning that the strength of distractor inhibition differed between age groups in the latency domain (see Distractor Relation  $\times$  Age Group interaction in Table 3 and distractor inhibition effects in Fig. 2A). Contrary to

**Table 3**

Summary table for 2 (Distractor Relation: repetition vs. change)  $\times$  2 (Response Relation: repetition vs. change)  $\times$  2 (Age Group: children vs. young adults) mixed-model ANOVA results on mean log-transformed probe RT and error rates in Experiment 1.

Variable	Log-transformed probe RT				% Probe errors			
	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
<i>Between participants</i>								
Age group (A)	1	386.94***	.83	.000	1	4.66*	.06	.034
Error (A)	79	(0.069)			79	(0.003)		
<i>Within participants</i>								
Distractor relation (D)	1	12.87**	.14	.001	1	0.87	.01	.354
Response relation (R)	1	393.34***	.83	.000	1	54.69***	.41	.000
D $\times$ A	1	4.46*	.05	.038	1	2.10	.03	.151
D $\times$ R	1	18.38***	.19	.000	1	3.69†	.05	.058
R $\times$ A	1	1.01	.01	.317	1	2.04	.03	.158
D $\times$ R $\times$ A	1	3.22†	.03	.076	1	0.37	.00	.543
Error (D)	79	(0.002)			79	(0.001)		
Error (R)	79	(0.016)			79	(0.002)		
Error (D $\times$ R)	79	(0.002)			79	(0.001)		

Note. Values enclosed in parentheses represent mean square errors. RT, reaction time.

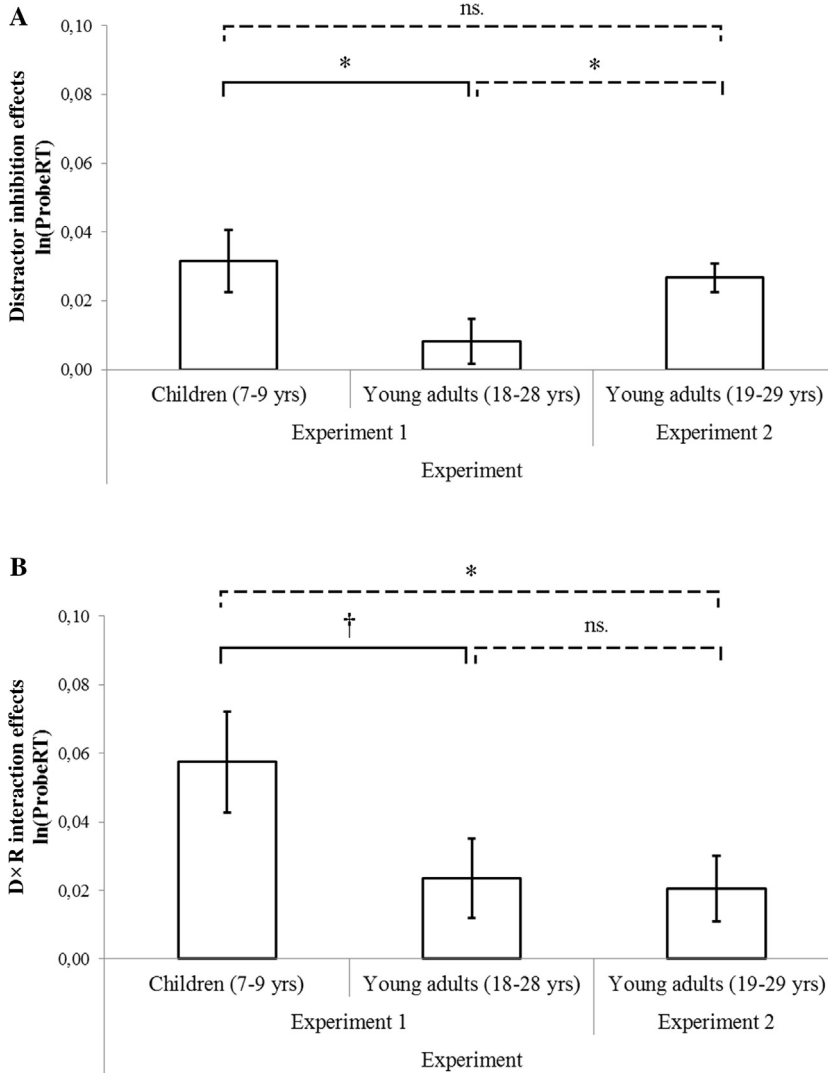
†  $p < .10$ .

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .





**Fig. 2.** (A) Distractor inhibition effects, computed as the difference of probe trials with distractor change (DC) minus probe trials with distractor repetition (DR), averaged across response relation (see Fig. 1 for details on effect computation), as a function of age group in Experiments 1 and 2. Positive values reflect probe performance benefits due to repeating a persistently inhibited prime distractor. (B) Episodic retrieval effects of distractor–response bindings [computed from  $D \times R$  interaction effects in the probe: (DCRR–DRRR) – (DCRC–DRRC)]. Positive values indicate interaction effects that conform with expected effects due to distractor-based response retrieval (i.e., positive distractor–response retrieval effects for response repetition sequences and negative distractor–response retrieval effects for response change sequences). Error bars depict standard errors. Solid brackets reflect ANOVA results from the age group comparison in Experiment 1. Brackets with dashed lines reflect results of planned contrasts from joint comparison of age groups across Experiments 1 and 2 (see main text for details). yrs, years.  $^{\dagger}p < .10$ ;  $^*p < .05$ ; ns. = not significant.

our first hypothesis, children showed a significantly stronger distractor inhibition effect [DI effect = 30 ms, which also significantly differed from zero;  $t(40) = 3.53$ ,  $p = .001$ ,  $d_z = 0.55$ ; see Fig. 1A for details on effect computation] than young adults [DI effect = 4 ms, which did not differ from zero;  $t(39) = 1.27$ ,  $p = .21$ ,  $d_z = 0.20$ ]. The same descriptive trend was apparent in the error data (see Table 2). Therefore, findings argue against a developmental inhibitory deficit in children.

*Episodic retrieval of distractor–response bindings.* Analysis further revealed a significant interaction between distractor relation and response relation for both RTs and errors ( $p = .029$ , one tailed; see Table 3), indicating episodic retrieval of distractor–response bindings (Rothermund et al., 2005). Follow-up tests showed that, compared with distractor changes, distractor repetition in the probe significantly facilitated performance on response repetition sequences and led to faster responses [ $\Delta\text{DCRR} - \text{DRRR} = 30$  ms;  $t(80) = 4.76$ ,  $p < .001$ ,  $d_z = 0.53$ ] and more accurate responses [ $\Delta\text{DCRR} - \text{DRRR} = 0.9\%$ ;  $t(80) = 1.99$ ,  $p = .049$ ,  $d_z = 0.22$ ]. In turn, distractor repetition had no effect on probe performance for response change sequences (RT:  $\Delta\text{DCRC} - \text{DRRC} = 5$  ms,  $|t| < 1$ ; errors:  $\Delta\text{DCRC} - \text{DRRC} = -0.8\%$ ;  $|t| < 1$ ). More important for the current purposes was whether the episodic retrieval effects differed between age groups (i.e., whether the three-way interaction was significant). Descriptively, the Distractor Relation  $\times$  Response Relation ( $D \times R$ ) interaction tended to be stronger in the child sample (RT:  $D \times R$  interaction effect = 38 ms; errors:  $D \times R$  interaction effect = 1.6%; see Fig. 1B for details on effect computation) compared with the young adult sample (RT:  $D \times R$  interaction effect = 11 ms; errors:  $D \times R$  interaction effect = 0.8%; cf. Fig. 2B). In line with our second hypothesis, however, the three-way interaction of distractor relation, response relation, and age group missed conventional levels of significance for RTs but was absent for error rates. In sum, these findings support the notion that episodic retrieval processes are already existent and functionally intact in children aged 7–9 years. No other effect was significant (see Table 3).

## Discussion

Using a distractor-to-distractor repetition paradigm (cf. Giesen et al., 2012), Experiment 1 aimed to dissociate processes of distractor inhibition and episodic retrieval and to compare both processes across different age groups. The obtained results are important in several respects. First, we found no evidence for an inhibitory deficit in children aged 7–9 years. To the contrary, distractor inhibition effects were not only present in the child sample but also appeared to be stronger than in the young adult sample. Second, we obtained no evidence for age group differences in episodic retrieval processes, suggesting that episodic binding and retrieval processes are already at work and functionally intact in children.

In addition, we obtained main effects of age group for RT and error rates, meaning that overall (a) children were slower than young adults and (b) children produced somewhat fewer errors than adults. Finding generally slower response latencies in children compared with young adults reflects typical age group-specific differences in processing speed that were also apparent in the fluid intelligence measure. In combination with the reduced error rate in children, however, this may be indicative of different speed–accuracy trade-offs in the respective age groups. To ascertain that these differences in speed–accuracy trade-offs between children and young adults do not affect the overall pattern of results, we repeated the analysis with inverse efficiency scores (IESs) as dependent variables (Townsend & Ashby, 1983). This was done to check whether the findings that were obtained for log-transformed probe RTs would replicate. As expected, analyses based on IESs closely replicated the overall pattern of effects obtained in the main analyses provided in the text.<sup>1</sup> Furthermore, error rates in principle mimicked the pattern of effects for distractor inhibition and episodic retrieval processes

<sup>1</sup> In detail, we first computed an IES for every condition of the factorial design and separately for each participant by dividing mean probe RT by the proportion of correct responses ( $\text{IES} = \text{RT}/\text{PC}$ ; cf. Townsend & Ashby, 1983). IESs were then entered as dependent variables into a 2 (Distractor Relation: repetition vs. change)  $\times$  2 (Response Relation: repetition vs. change)  $\times$  2 (Age Group: children vs. young adults) ANOVA. As concerns the effects of interests, this analysis yielded a main effect of distractor relation,  $F(1, 79) = 14.23$ ,  $p < .001$ ,  $\eta_p^2 = .15$ , due to lower IESs for distractor repetition probes compared with distractor change probes, which reflects a pattern of distractor inhibition. Importantly, this effect was qualified by age group, as indicated by a significant Distractor Relation  $\times$  Age Group interaction,  $F(1, 79) = 11.15$ ,  $p = .001$ ,  $\eta_p^2 = .12$ , meaning that distractor inhibition effects were larger for children than for young adults. Furthermore, we also obtained a significant Distractor Relation  $\times$  Response Relation interaction,  $F(1, 79) = 12.58$ ,  $p = .001$ ,  $\eta_p^2 = .14$ , indicating episodic retrieval of distractor–response bindings. Follow-up tests showed that, compared with distractor changes, distractor repetition probes facilitated performance on response repetition probes,  $t(80) = 4.93$ ,  $p < .001$ ,  $d_z = 0.55$ , but had no effect on response change probes ( $|t| < 1$ ,  $p = .79$ ). Importantly, however, the three-way interaction of distractor relation, response relation, and age group was not significant,  $F(1, 79) = 2.86$ ,  $p = .095$ ,  $\eta_p^2 = .04$ , indicating that episodic retrieval effects of distractor–response bindings did not differ between children and young adults in Experiment 1. Taken together, analyses based on IESs closely replicated the results of the main analyses reported in the text.

that were obtained for response latencies, although they were somewhat less reliable. Taken together, these results support the conclusion that differences in speed–accuracy trade-offs between children and young adults did not affect the overall pattern of results.

Somewhat surprisingly, we found no effects of distractor inhibition in the sample of young adults. This finding is at odds with two existing studies (Giesen et al., 2012, 2015) that yielded robust and reliable distractor inhibition effects in young adults with the current paradigm. However, these former studies varied the location of the stimulus triplet across trials to reduce spatial selection of target stimuli. In contrast, stimulus triplets constantly appeared at a central position in the current experiment. This was done to make the task easier for children. By implication, however, the task also became easier for young adults, who might have used this simplification to their advantage. For instance, they could have adopted a “zooming in” or “focusing” strategy that allowed selecting target stimuli based on their absolute spatial position on the screen (Gibbons & Frings, 2010). Such a strategy would proactively block the processing of distractor stimuli so that reactive distractor inhibition would no longer be required. To test for this possibility, we ran a control experiment with a new sample of young adults in which we randomly varied the location of stimulus triplets for each trial as in the initial study (cf. Giesen et al., 2012). Effectively, participants need to maintain a broader focus to perform the task. Because “zooming in” is no longer possible in such a setup, effects of distractor inhibition should reoccur in the young adult sample for a variant of the paradigm that contains spatial uncertainty.

To test this, we performed a joint analysis of the data from Experiments 1 and 2, in which we decomposed the age group factor into two a priori orthogonal contrasts: The first contrast compares the child sample (Experiment 1) with the new young adult sample (Experiment 2), whereas the second contrast directly compares young adults from Experiments 1 and 2. The joint analysis tested the following predictions. First, if Experiment 2 prevented young adults from using a “zooming in” strategy, they should show larger distractor inhibition effects than the young adults of Experiment 1. Statistically, this hypothesis corresponds to an interaction of distractor relation and age group for the second contrast. Furthermore, the first contrast for this interaction allows for a direct comparison of distractor inhibition effects in children (Experiment 1) and young adults (Experiment 2). Second, we expected that episodic binding and retrieval processes (which are indicated by a Distractor Relation  $\times$  Response Relation interaction) should be intact already in children and should not differ from those of young adults. Statistically, this hypothesis is reflected in the absence of a three-way interaction of distractor relation, response relation, and age group for both contrasts.

## Experiment 2

### *Method*

#### *Participants*

A total of 40 new students (20 women;  $M_{\text{age}} = 23.3$  years, range = 19–29 years) of FSU Jena were recruited for the young adult sample in Experiment 2. Testing conditions, duration, and payment paralleled those of the student sample in Experiment 1.

#### *Materials, design, and procedure*

The materials, design, and procedure were similar to those in Experiment 1 except for the following changes. For every trial of the flanker task, the position of stimulus triplets varied randomly (cf. Giesen et al., 2012, Experiment 1). That is, stimulus triplets could appear 30 pixels to the left, right, above, or below the screen center (covering an area of 4.6 degrees vertically  $\times$  6.3 degrees horizontally) to prevent purely location-based selection of targets (Gibbons & Frings, 2010). Consequently, the position of stimulus triplets repeated from trial<sub>*n*</sub> to trial<sub>*n*+1</sub> in 25% of all sequences but changed in 75% of all transitions from trial<sub>*n*</sub> to trial<sub>*n*+1</sub>. Because position relation (repetition vs. change) did not interact with the factors of interest, it was not incorporated into the final analyses. Like in Experiment 1, participants were first given the color naming task (for results and a comparison with Experiment 1, see Table 2)

and then worked through the computer experiment. Further procedural details (practice, trial procedure, rewarding, and debriefing of participants) corresponded to those in Experiment 1.

## Results

### Data preparation

According to the same criteria as in Experiment 1, 10.5% of probe trials were excluded because of erroneous responses in the prime and/or probe; in addition, 3.9% of trials were excluded because of RT outlier values. Like in Experiment 1, we computed means of log-transformed probe RTs for every cell of the factorial design and separately for each participant (see Table 2). The changes in Experiment 2 should lead to a reoccurrence of distractor inhibition in the new young adult sample. To examine age group-dependent and experiment-specific differences in distractor inhibition and episodic retrieval effects, data of this new young adult sample were compared with both samples from Experiment 1 in a joint analysis. In detail, we performed a 2 (Distractor Relation: repetition vs. change)  $\times$  2 (Response Relation: repetition vs. change)  $\times$  3 (Age Group: children [Experiment 1] vs. young adults [Experiment 1] vs. young adults [Experiment 2]) mixed-model multivariate analysis of variance (MANOVA) on mean log-transformed probe RTs and mean probe error rates. Global MANOVA results are shown in Table 4. To allow for a more fine-grained analysis of age- and experiment-specific effects, the age group factor was decomposed into two *a priori* orthogonal contrasts: “children (Experiment 1) versus young adults (Experiment 2)” (first contrast) and “young adults (Experiment 1) versus young adults (Experiment 2)” (second contrast).

### Probe performance

Before presenting results (descriptive and statistical tests) for distractor inhibition and episodic retrieval effects, we again briefly report results for additional main effects unrelated to the effects of interest.

As can be seen in Table 4, analyses revealed that, overall, participants responded faster and more accurately on response repetition probes ( $M = 596$  ms and  $M = 2.3\%$ , respectively) compared with response change probes ( $M = 779$  ms and  $M = 6.2\%$ ), as indicated by a main effect of response relation for RTs and errors. Furthermore, children were again slower ( $M = 975$  ms) than young adults

**Table 4**

Summary table for 2 (Distractor Relation: repetition vs. change)  $\times$  2 (Response Relation: repetition vs. change)  $\times$  3 (Age Group: children [Experiment 1] vs. young adults [Experiment 1] vs. young adults [Experiment 2]) mixed-model MANOVA results on mean log-transformed probe RT and error rates.

Variable	Log-transformed probe RT				% Probe errors			
	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
<i>Between participants</i>								
Age group (A)	2	289.63***	.83	.000	2	2.39 <sup>†</sup>	.04	.096
Error (A)	118	(0.06)			118	(0.00)		
<i>Within participants</i>								
Distractor relation (D)	1	29.17***	.20	.000	1	0.73	.01	.396
Response relation (R)	1	642.34***	.84	.000	1	106.61***	.48	.000
D $\times$ A	2	3.02 <sup>†</sup>	.05	.053	2	1.10	.02	.337
D $\times$ R	1	22.91***	.16	.000	1	7.26***	.06	.008
R $\times$ A	2	0.85	.01	.429	2	2.15	.04	.121
D $\times$ R $\times$ A	2	2.83 <sup>†</sup>	.05	.063	2	0.27	.00	.787
Error (D)	118	(0.00)			118	(0.00)		
Error (R)	118	(0.01)			118	(0.00)		
Error (D $\times$ R)	118	(0.00)			118	(0.00)		

Note. Values enclosed in parentheses represent mean square errors. RT, reaction time.

<sup>†</sup>  $p < .10$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .

(Experiment 1:  $M = 535$  ms; Experiment 2:  $M = 552$  ms), which was reflected in a significant main effect of age group for RT only (see Table 3). This effect was due to the first contrast, which was significant,  $t(118) = 20.15$ ,  $p < .001$ ,  $d = 4.51$ , whereas the second contrast was not significant,  $|t| < 1$ . In other words, children were significantly slower than young adults in Experiment 2, whereas young adults in Experiments 1 and 2 did not differ in their response latencies.

*Distractor inhibition effects.* In addition, participants responded faster in probe trials with distractor repetition ( $M = 679$  ms) compared with distractor change ( $M = 695$  ms), as indicated by a significant main effect of distractor relation in the latency domain (but not for errors), which reflects a pattern of distractor inhibition. In contrast to Experiment 1, which revealed significant distractor inhibition effects in RTs only for children (DI effect = 30 ms) but not for young adults (DI effect = 4 ms), the distractor inhibition effects for RTs in the young adult sample of Experiment 2 was now reliable (DI effect = 15 ms) and differed significantly from zero,  $t(39) = 5.05$ ,  $p < .001$ ,  $d_z = 0.80$ . This pattern was also statistically reliable given that for RTs, but not for errors, the main effect of distractor relation was further qualified by age group (Table 4). For RTs, planned contrasts revealed that the Distractor Relation  $\times$  Age Group interaction was significant for the second contrast,  $t(118) = 1.83$ ,  $p = .034$  (one tailed; see Fig. 2A),  $d = 0.41$ . In line with our first prediction, distractor inhibition effects for the young adult sample in Experiment 2 were significantly stronger than those for the young adult sample in Experiment 1. Importantly, the Distractor Relation  $\times$  Age Group interaction was not significant for the first contrast,  $|t| < 1$ ,  $d = 0.11$ , meaning that distractor inhibition effects did not differ statistically for the age group comparison of “children versus young adults (Experiment 2).” These findings indicate that young adults show reliable effects of distractor inhibition when spatial selection of targets is prevented as a strategy. More important, the size of distractor inhibition was of the same magnitude in young adults and children. For errors, none of the contrast tests yielded significant results (all  $|ts| < 1.05$ ,  $ps > .29$ ).

*Episodic retrieval of distractor–response bindings.* Analyses further revealed a significant interaction of distractor relation and response relation for RTs and errors, indicating episodic retrieval of distractor–response bindings. Follow-up tests showed that, compared with distractor change, distractor repetition in the probe facilitated performance in response repetition sequences and led to faster responses [ $\Delta DCRR - DRRR = 26$  ms;  $t(120) = 6.15$ ,  $p < .001$ ,  $d_z = 0.56$ ] and more accurate responses [ $\Delta DCRR - DRRR = 0.9\%$ ;  $t(120) = 2.42$ ,  $p = .017$ ,  $d_z = 0.22$ ]. In turn, distractor repetition had no effect on response change sequences [RT:  $\Delta DCRC - DRRC = 7$  ms;  $t(120) = 1.18$ ,  $p = .24$ ,  $d_z = 0.11$ ; errors:  $\Delta DCRC - DRRC = -0.5\%$ ;  $t(120) = 1.37$ ,  $p = .18$ ,  $d_z = 0.12$ ]. For RTs, the Distractor Relation  $\times$  Response Relation interaction differed significantly from zero in all age groups [children:  $D \times R$  interaction effects = 38 ms;  $t(40) = 3.88$ ,  $p < .001$ ,  $d_z = 0.61$ ; young adults, Experiment 1:  $D \times R$  interaction effects = 11 ms;  $t(39) = 2.02$ ,  $p = .026$ , one tailed,  $d_z = 0.32$ ; young adults, Experiment 2:  $D \times R$  interaction effects = 8 ms;  $t(39) = 2.15$ ,  $p = .038$ ,  $d_z = 0.34$ ]. To test our second prediction (i.e., whether the Distractor Relation  $\times$  Response Relation interaction effects differed significantly between age groups), we decomposed the three-way interaction (see Table 4) into the two planned contrasts. With respect to the latency domain, planned contrasts showed that Distractor Relation  $\times$  Response Relation interaction effects were qualified by age group for the first contrast,  $t(118) = 2.13$ ,  $p = .03$ ,  $d = 0.47$ . This means that episodic binding and retrieval effects were significantly stronger in the child sample compared with the young adult sample of Experiment 2 (see Fig. 2B). In turn, the three-way interaction was not significant for the second contrast,  $|t| < 1$ ,  $d = 0.03$ , meaning that episodic binding and retrieval effects did not differ between the young adult samples in Experiments 1 and 2 (Fig. 2B). Together, these findings suggest that episodic binding and retrieval effects are functionally intact already in children. For errors, none of the contrast tests yielded significant results (all  $|ts| < 1$ ,  $ps > .51$ ). No other effects were significant (see Table 4).

## Discussion

The results of Experiment 2 are clear-cut; we obtained reliable distractor inhibition effects in the new young adult sample when the experimental design prevented a purely spatial selection of target

stimuli. This was achieved by randomly varying the position of stimulus triplets on the screen (Gibbons & Frings, 2010; Giesen et al., 2012, 2015). Moreover, the amount of distractor inhibition shown by young adults who participated in Experiment 2 was comparable in size to the amount of distractor inhibition shown by children. In turn, episodic binding and retrieval effects were significantly smaller in the young adult sample of Experiment 2 than in the child sample. This trend was also (descriptively) present in Experiment 1 and is supported by finding no statistical differences in episodic retrieval effects between the young adult samples in Experiments 1 and 2. We come back to this point in the General Discussion. More important in the current context, however, is the observation that we obtained robust episodic retrieval effects in the child sample.

Therefore, we can draw the following conclusions. First, in comparison with young adults, children do not show any inhibitory deficits. Second, children apparently did not adopt a proactive selection strategy (e.g., spatial target selection). If that were the case, we should not have obtained distractor inhibition effects in the child sample. Therefore, the current data support the claim that reactive distractor inhibition is fully functional in children. Third, the current findings further support the conclusion that episodic binding and retrieval effects are already present and functionally intact in 7- to 9-year-old children and are comparable (at a minimum) to those of young adults.

## General discussion

The current study aimed to investigate whether children (aged 7–9 years) show deficits in distractor inhibition or not compared with young adults (aged 18–29 years). Therefore, we created a version of the distractor repetition paradigm of Giesen et al. (2012, Experiment 1) that was suitable for children, which allowed us to dissociate processes of distractor inhibition and episodic retrieval and provided independent measures for both processes. Data of two experiments yielded the following results. First, we obtained no evidence for distractor inhibition deficits in the child sample. This is based on finding robust performance benefits on distractor repetition probes compared with distractor change probes in children, indexing persistent inhibition of prime distractors during probe presentation. A noteworthy finding is that these effects tended to be even stronger in children compared with the young adult sample, who showed no distractor inhibition effects in Experiment 1. However, data from another control experiment indicate that this null finding in the young adult sample most likely stemmed from a proactive “focusing” strategy used by young adults that rendered distractor inhibition unnecessary. Comparing children’s distractor inhibition effects with those of young adults who were prevented from adopting such a selection strategy (Experiment 2) showed that distractor inhibition effects were of comparable magnitude in children and young adults. In combination, both experiments suggest that children apparently did not develop or adopt any proactive selection strategy (e.g., spatial target selection) but instead used reactive distractor inhibition to deal with interference from response-incompatible distractors.

Although our findings do not support the claim of an inhibitory deficit in children, it should be noted that our study investigated only children who were at least 7 years old. Thus, it is possible that inhibitory deficits can be detected in children who are even younger. It may seem somewhat unlikely, however, to expect deficits of inhibition in even younger children given that they learn to suppress “forbidden” behaviors and responses already at very young ages.

Notably, our data yield no consistent evidence for age group differences in episodic binding and retrieval effects, although this interpretation rests on null findings (i.e., the absence of a three-way interaction among distractor relation, response relation, and age group). A post hoc power analysis with G\*Power 3.1 software (Faul, Erdfelder, Lang, & Buchner, 2007) showed that the achieved power for the age group comparisons for episodic retrieval effects was not ideal (i.e., the probability to detect a medium-sized effect of  $f = .25$  was  $1 - \beta > .72$  in Experiment 1 and  $1 - \beta > .71$  for the planned contrasts tests in Experiment 2). Therefore, it is possible that we would have detected age group differences in episodic binding and retrieval effects with a larger sample size. Note, however, that the actual pattern of episodic retrieval effects tended to be larger in the child sample compared with the samples of young adults. Note also that the size of episodic retrieval effects in young adults was smaller than in previous studies (e.g., Giesen et al., 2015, reported a  $D \times R$  interaction effect of



46 ms for young adults, which is much more similar to the  $D \times R$  interaction effect of 38 ms we obtained for children). Currently, we can only speculate as to why episodic retrieval effects were smaller in the young adult samples. First of all, it is striking that, on average, young adults' responses were 400–500 ms faster than children's responses. This means that the time window for episodic retrieval processes to influence performance was considerably shortened in the young adult groups. Second, and contrary to two previous studies (Giesen et al., 2012, 2015), prime–probe sequences were less distinct in the current setup due to the successive trial sequence, which is known to impair episodic retrieval processes (Neill et al., 1992). Therefore, it is likely that age group–specific differences in overall response speed in combination with the consecutive trial design were detrimental for episodic retrieval processes in young adults, which accounts for the considerably smaller effects in both young adult samples. More important for the current purposes, however, is the fact that we obtained reliable episodic retrieval effects in the child sample. The current finding nicely fits with other studies that reported intact automatic binding and retrieval processes already in very young children, that is, from the age of 4 years onward (Eenshuistra, Weidema, & Hommel, 2004; Karbach, Kray, & Hommel, 2011). Therefore, we can conclude that automatic processes of stimulus–response binding and retrieval are present and functionally intact already at a young age.

According to the episodic retrieval account, retrieval of distractor–response bindings due to distractor repetitions should produce probe performance benefits (i.e., facilitation effects) in response repetition sequences but should lead to probe performance costs (i.e., interference effects) in response change sequences (cf. Fig. 1B). For all age groups of the current study, however, only facilitation effects were significant, whereas interference effects were not significant. At first sight, this observation seems to contradict the episodic retrieval of distractor–response bindings. Yet, it is important to keep in mind that in addition to episodic retrieval effects, distractor inhibition had a *general facilitatory* influence on distractor repetition probes (affecting response repetition and change sequences to an equal extent). A possible explanation could be that distractor inhibition and episodic retrieval effects added up to each other on response repetition sequences (and boosted facilitation effects) but canceled each other out in response change sequences (resulting in null findings instead of interference effects; see also Giesen & Rothermund, 2016, for a detailed discussion). Of course, we cannot be sure whether both processes are of exactly the same strength (which would explain the null findings in response change sequences); it is still possible that additional processes unrelated to inhibition and retrieval were also involved in bringing about the effects. Irrespective of these speculations, the most stringent test for episodic retrieval of distractor–response bindings is the Distractor Relation  $\times$  Response Relation interaction, which tests the *difference* between probe performance benefits and costs due to distractor repetitions. Notably, this interaction was highly significant in each age group (see Results section of Experiment 2).

The current experiments endorsed an “asymmetrical” factorial design, meaning that the frequencies of the four different trial types (DRRR, DRRC, DCRR, and DCRC) differed (see Method section of Experiment 1). We purposefully chose this factorial design to rule out any influence of strategic expectations: That is, the percentage of distractor repetitions (25%) and response repetitions (25%) corresponded exactly to chance or base rate probabilities if four stimuli are mapped onto four responses. This guarantees that neither the response nor the distractor in trial<sub>n</sub> can be predicted based on the stimuli presented in the preceding trial<sub>n-1</sub>. Nevertheless, one might feel tempted to think that participants developed a tendency (or strategy) to expect response changes by default given that response repetitions were less frequent than response changes (25% vs. 75%). Yet, we believe that such a strategic response tendency is highly unlikely to occur in our task for the following reasons. First, expecting a response change from trial<sub>n-1</sub> to trial<sub>n</sub> still allows no accurate prediction as to *which* of the three alternative responses will be correct in trial<sub>n</sub>. Because base rate probabilities are preserved, all three alternative responses are equally likely on response change trials (and each of them is exactly as likely as the repetition of the prime response). Second, participants always responded faster for trial sequences with response repetitions than with response changes. Thus, the empirical data argue strongly against a strategic expectation or preparation of response changes from one trial to the next. A similar rationale applies to the distractor relation factor (although distractor changes have a higher probability of occurrence than distractor repetitions [75% vs. 25%], this does not allow for any strategic prediction of the probe distractor because there are three different possible distractors that can be



presented in a distractor change trial). Hence, the decision to use base rate probabilities for stimulus and response repetitions renders alternative explanations in terms of strategic responding or expectancy-based preparations unlikely or even impossible.

### *Theoretical implications*

On a more general basis, the current findings can be seen as a conceptual replication of [Giesen et al. \(2012, 2015\)](#). On the one hand, this validates the paradigm's merit for experimentally dissociating distractor inhibition and automatic binding/retrieval processes. Our findings substantiate the conclusion that both of these processes reflect independent processes that operate in the service of efficient behavior regulation. In this regard, the current findings also provide meaningful insight into the nature of the underlying processes. Our findings support the view that distractor inhibition (as measured with the current paradigm) is "reactive" in the sense that it "shields" selection of the target response from interfering (viz. response-incompatible) distractor stimuli. Because response-incompatible distractors are associated with responses themselves, they pose a threat during response selection and may lead to the selection of an incorrect response. Distractor inhibition counteracts this interference, meaning that the distractor is no longer translated into "its" associated response (e.g., [Tipper & Cranston, 1985](#); see also [Giesen et al., 2012](#), for a detailed discussion). Importantly, this does not preclude any further processing of distractor stimuli (i.e., distractor inhibition does not imply that the distractor's mental representation becomes "deactivated" altogether; cf. [Houghton & Tipper, 1994](#)). In the current data, this is highlighted by the fact that (even inhibited) distractors became the subject of episodic binding and retrieval processes.

Furthermore, the insight that processes of both distractor inhibition and episodic retrieval are already apparent and detectable in young children is particularly important; it implies that previous findings on distractor inhibition abilities in children that are based on the negative priming paradigm ([Frings, Feix, et al., 2007](#); [Pritchard & Neumann, 2004, 2009](#); [Simone & McCormick, 1999](#)) need to be treated with caution. Based on the results of our study, it is very likely that the reported negative priming effects in children may stem from distractor inhibition, episodic retrieval, or a combination of both processes. Negative priming effects, therefore, provide no unambiguous evidence for possible age-specific differences in distractor inhibition abilities. The current study illustrates that the adopted distractor repetition paradigm by [Giesen et al. \(2012\)](#) is a versatile tool to investigate distractor inhibition and episodic retrieval processes in an unbiased way and, therefore, is a superior alternative to the negative priming paradigm. This is further supported by a recent adaption of the distractor repetition paradigm in the tactile stimulus modality to investigate aftereffects of tactile distractor processing ([Wesslein, Moeller, Frings, & Giesen, submitted for publication](#)), which reflects a direct replication of findings from the domain of visual stimulus processing. Together, this points toward the possibility that distractor inhibition represents a global and modality-*unspecific* process. In this regard, it would be interesting to know whether inhibitory abilities across different modalities are (positively) related within a person and transfer from one stimulus modality to the other. Ultimately, these findings attest that the distractor repetition paradigm is suitable for the study of distractor inhibition and episodic retrieval processes in participants across a wide age range (e.g., 7–87 years) and within diverse stimulus modalities.

The current findings seemingly contrast with other studies that report age-related differences for children aged 4–13 years in measures of interference control. For instance, flanker interference effects show a negative age trend and become smaller as children grow older; even children older than 9 years show this negative age trend (e.g., [Checa, Castellanos, Abundis-Gutiérrez, & Rosario Rueda, 2014](#); [Ridderinkhof, van der Molen, Band, & Bashore, 1997](#)). The same holds true for Stroop-like interference effects ([Gerstadt, Hong, & Diamond, 1994](#)) or Simon effects ([Rubia et al., 2006](#)). Interference paradigms are often used as indicators of inhibitory processes; it is assumed that interference from an irrelevant stimulus (or stimulus dimension) needs to be "overcome" (i.e., inhibited) in order to perform well in the task. In this respect, large interference effects are typically interpreted as indicating poor inhibitory abilities. Although plausible, it is likely that interference paradigms themselves are no process-pure indicator of inhibition either. For instance, a range of other processes relating to processes of selective attention (e.g., prioritization of task-relevant stimuli/dimensions, attentional

focusing, susceptibility to response competition) might be at work and contribute to the effects (cf. Egner & Hirsch, 2005; for a discussion, see also Schuch & Konrad, 2017).

Age-related differences are also reported with respect to the ability to inhibit a prepared response. For instance, children's performance in the stop signal task or in the go/no-go task is assumed to improve with increasing age (e.g., see National Survey of Child & Adolescent Well-Being, 2009; Ridderinkhof, Band, & Logan, 1999; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). According to Williams et al. (1999), who studied stopping performance in participants aged 6–81 years, this improvement is due to the fact that the inhibition process becomes faster (i.e., more efficient) as children grow older. However, other developmental studies failed to find age-dependent effects (Schachar & Logan, 1990; for a discussion, see also Ridderinkhof et al., 1999).

Interestingly, a very recent study by Schuch and Konrad (2017) investigated age-dependent differences in the ability to inhibit an entire task (also labeled “backward inhibition” or “ $n - 2$  repetition costs”; see Koch, Gade, Schuch, & Philipp, 2010). Accordingly, backward inhibition effects (in terms of RTs and errors) in children (aged 9–11 years) were comparable to those in young adults (aged 21–30 years). However, diffusion model and ex-Gaussian analyses suggested that backward inhibition effects were mediated by different cognitive processes in children and young adults.

Summing up, it becomes apparent that evidence for age-related differences in inhibitory abilities is mixed and quite heterogeneous. Importantly, this problem occurs not only for comparisons of findings across various paradigms but also for studies that adopt the very same paradigm. This ambivalence in empirical findings is particularly dramatic for the negative priming paradigm. Against this background, therefore, the current study had the aim to illustrate that a dissociation of different underlying processes is possible and may actually help us to get one step closer to understanding their developmental changes. However, more data are needed to evaluate the extent to which distractor inhibition (as measured with the current distractor repetition paradigm), response inhibition (as measured with the stop signal task), and task inhibition (as reflected in  $n - 2$  repetition costs) reflect the same versus distinct underlying cognitive abilities (cf. Friedman & Miyake, 2004) and how they develop.

### *Conclusions and outlook*

In accordance with most of the previous literature on negative priming, our findings provide further evidence for fully functioning inhibition processes in children at the elementary school age. The advantage of our study is that we used an index of inhibition that is process pure and is not confounded with memory processes of episodic stimulus–response binding and retrieval. Still, it would be premature to discard the hypothesis of age differences in cognitive development altogether. The previous discussion of findings from other paradigms, which are assumed to measure aspects of inhibitory abilities, underlines this reasoning. Phenomenologically, at least, the observation that children are more susceptible to distraction than adults appears to be an undisputable fact for everyone who has frequent experience with children in everyday life. These everyday experiences are perhaps a major reason why the hypothesis of deficient inhibition in children has retained its plausibility and has been entertained again and again, mostly in textbooks, despite the somewhat ambivalent evidence in the literature.

In conclusion, then, it seems wise to take a more differentiated stance on this issue. What our study showed is that *reactive* inhibition is operative in children and young adults likewise. However, what our study also revealed, although only indirectly, is that adults tend to use attentional selection in a more efficient way than children; that is, if the spatial position of distracting information is predictable (as in Experiment 1), adults make use of this predictability and activate selection strategies to filter these distractors even before they can interfere with actual performance. Children apparently do not possess the ability to use this attentional selection strategy, or they use it less efficiently than adults, as was recently demonstrated in a study showing that children are more susceptible to attentional capture by irrelevant cues than adults, indicating a deficit with regard to strategies of spatial attentional focusing (Gaspelin, Margett-Jordan, & Ruthruff, 2015). Therefore, they need to cope with this situation by suppressing the flanker stimuli that are already exerting interference in response selection or that are being experienced as distracting, which is why we find clear evidence for retroactive inhibition in children in this study.

Thus, the current study provides convincing evidence that observable differences in behavior between children and adults regarding a global, trait-like disposition of distractibility should not be attributed to differences in reactive inhibition. Instead, our findings seem to suggest—at least tentatively—that these differences might reflect age differences in developing and using strategies of selective attention.

Stated in developmental terms, our findings suggest that processes of cognitive control develop “from output (i.e., responses) to input (i.e., stimulus) control”; that is, children first learn to control their behavior by reactive processes like inhibition and suppression. Learning not to respond in a certain way and to suppress a behavioral tendency because adults say “no!” whenever you execute this action is a very early achievement of behavioral response control. This form of pure response inhibition is then followed by the ability to suppress the processing of environmental cues that might prompt such forbidden behaviors. Again, this form of control probably precedes more sophisticated strategic processes of early cognitive and environmental control. Only much later do children develop strategies that allow them to focus their attention selectively on relevant information and to prevent irrelevant information from entering initial stages of processing completely.

Thus, although there is now some evidence attesting to an “inhibitory deficit” during old age (Lustig, Hasher, & Zacks, 2007), our findings do not provide support for a corresponding deficit in children. Rather than explaining the increased distractibility of young children and older adults in terms of a common principle (“last in–first out”; Raz, 2000), our findings rather suggest that the two phenomena need to be explained differently. Whereas a deficit in strategic attentional focusing on relevant information accounts for increased distractibility in children, the very same phenomenon is due to a “loss of inhibition” (Giesen et al., 2015) in older adults.

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